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Proceedings—Symposium on the Management of Lodgepole Pine to Minimize Losses to the Mountain Pine Beetle

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COVER PHOTO: Creation of a mosaic of age and size classes, and species diversity, is one of the best long-term strategies for minimizing lodgepole pine losses to the mountain pine beetle.

Proceedings—Symposium on the Management of Lodgepole Pine to Minimize Losses to the Mountain Pine Beetle

Kalispell, MT, July 12-14, 1988

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FOREWORD

Recent progress in management strategies to mitigate impacts of mountain pine beetle infestations prompted this symposium. Significant progress has been made in the areas of hazard-rating stands for beetle infestations, and silvicultural, chemical, and pheromone methods of reducing infestations and protecting trees.

This symposium was a success because of the whole-hearted cooperation of speakers, moderators, participants, and support staff. The following deserve special recognition:

Program Chairman: Dave Holland, Group Leader, Forest Pest Management, State and Private Forestry, Intermountain Region, Forest Service, Ogden, UT.

Local Arrangements: Jed Dewey, Entomology Group Leader, Cooperative Forestry and Pest Management, Northern Region, Forest Service, Missoula, MT; Jim VanDenburg, Forest Silviculturist, Flathead National Forest, Kalispell, MT.

Field Trips: Ken Gibson, Entomologist, Cooperative Forestry and Pest Management, Northern Region, Forest Service, Missoula, MT; Barry Bollenbacher, Silviculturist, Flathead National Forest, Big Fork, MT.

Gene D. Amman
Proceedings Compiler

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CANADA/U.S. MOUNTAIN PINE BEETLE/LODGEPOLE PINE PROGRAM 1981-1988

David A. Graham and Gordon Miller

ABSTRACT: Concerns over widespread mountain pine beetle outbreaks in the 1970's and early 1980's motivated the Forest Service, U.S. Department of Agriculture, and the Canadian Forestry Service to initiate a joint program to mitigate lodgepole pine losses caused by the insect. Since 1981, cooperative work in the program has resulted in many accomplishments. Although hampered by funding problems, program chairmen from the two Nations expect additional progress in the future.

BACKGROUND

Mountain pine beetle outbreaks have occurred rather frequently in both the western United States and western Canada throughout recorded history. Some have been rather localized, others have covered vast acreages often followed by catastrophic wild fires, mostly in the United States. During the 1970's, severe outbreaks began to develop in a number of areas in the State of Montana, including Glacier and Yellowstone National Parks. By 1980, some 4 million acres in Montana were severely affected by the mountain pine beetle. During the late 1970's, outbreaks were beginning to occur in both increasing numbers and size in Canada--especially in British Columbia and just north of the Canada/U.S. border in Waterton Lakes National Park, Alberta, and adjacent areas. Widespread tree-killing resulted in increasing media and political attention during 1979, 1980, and 1981. A number of Canadians were expressing considerable concern over "the lack of aggressive control action in the United States," particularly in Glacier National Park and in the North Fork of the Flathead River.

Two key forestry coordination and information exchange meetings between U.S. Forest Service and Canadian Forestry Service officials that brought this subject up for possible resolution were held in Washington, DC, on November 4, 1980, and in Ottawa, Canada, on June 22-23, 1981. A followup meeting was also held in Victoria, Canada, on February 15, 1982, in conjunction with the North American Forestry Conference. U.S. Forest Service Chief Max Peterson, Assistant Deputy Minister (ADM) for the Canadian Forestry Service Les Reed, and key members of their staffs were in attendance at all of these meetings. The concern and need for action expressed by the two countries over the mountain beetle situation was recorded in the minutes of the 1981 Ottawa meeting as follows:

> The Mountain Pine Beetle Program. The Mountain Pine Beetle problem in Western Canada is becoming acute as the beetle moves from the United States to Canada along the Rocky Mountains in both British Columbia and Alberta. It is a problem that is gaining a great deal of political visibility in Canada, even as it did earlier in the United States. The ADM and Chief agreed that there were opportunities here for important joint collaboration between the two countries, perhaps similar to the work already done under CANUSA (Canada/U.S. Spruce Budworm Program). Several points came up as follows:
>
> a. That the R&D review now being performed by the USFS (in cooperation with Canada) would be completed in about a month and this would serve as a point of departure not only for R&D work, but for application and full-scale operational work as well.
>
> b. The two countries could convene a state-of-the-art review in perhaps 3 months in Canada or the United States. In any event, this review of the state-of-the-art would involve political and land management leaders of both countries and would serve as a departure point for the next step in collaboration.
>
> c. There would be no objections to a CANUSA-like program; however, we would draw on improving the operating procedures of the CANUSA program if a Mountain Pine Beetle program were launched.
>
> d. Chief Peterson is to write a letter to ADM Reed outlining how we see the next steps in initiating a joint program on the mountain pine beetle.
>
> e. We would try to bring mountain pine beetle work under a blanket overall agreement between the two countries--the mountain pine

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Presented at the Symposium on the Management of Lodgepole Pine to Minimize Losses to Mountain Pine Beetle, Kalispell, Montana, July 12-14, 1988.

David A. Graham is Director of State and Private Forestry, Intermountain Region, USDA-Forest Service, Ogden, Utah. Gordon Miller is Program Director, Forest Protection Research, Canadian Forestry Service, Pacific Forestry Centre, Victoria, British Columbia, Canada. They are Co-chairmen of the Canada/U.S. Mountain Pine Beetle Program for the two respective countries.

beetle agreement being the first amendment under such an overall accord. A proposed mountain beetle US/Canadian agreement was given to Brandt and Anderson.

Thus, it was agreed at the Ottawa meeting that efforts to mitigate mountain pine beetle-caused losses to lodgepole pine and related resources could be enhanced and made more effective by improving inter-country coordinating mechanisms, and through more wide-spread sharing of knowledge and scientific talent. The letter from Chief Peterson to ADM Reed, outlining the process for initiating a joint program was transmitted to Canada on August 25, 1981.

The letter stressed the immediate need to aggressively implement salvage and fire hazard reduction programs, to increase thinning of younger lodgepole pine stands, and to improve utilization of the species. The emphasis focused on improving the economic situation and providing better access to and within the many unroaded forested areas. The letter included a proposed Memorandum of Understanding (MOU) covering specific mountain pine beetle/lodgepole pine management cooperation needs and accomplishment authorities. This MOU became a supplement to an overall MOU between Canada and the United States covering the entire field of forestry. These documents, covering a 5-year period, were approved by both countries during June 1982. The supplemental MOU on mountain pine beetle, was also signed by all border States and Provinces involved (Washington, Idaho, Montana, British Columbia, and Alberta). This later document has now become a "Project Agreement" supplementing the overall forestry cooperation MOU. Both documents were recently approved by both countries for another 5-year period.

ACTIVITIES

The first step of the original initiative was a "state-of-the-art" meeting which was held at Fairmont Hot Springs, British Columbia, on November 3-4, 1981. This included a very informative field trip demonstrating Canadian control efforts and considerable press coverage. A complete proceedings was published by the Canadian Forestry Service: "Proceedings of the Joint Canada/U.S.A. Workshop on Mountain Pine Beetle Related Problems in Western North America (BC-X-230), 1982." The approximately 70 participants included State Governor and Provincial government representatives as well as all concerned land management agencies and private industry. To provide continuity and to facilitate the overall implementation and coordination of this program, a joint Canada/U.S. Lodgepole Pine/Mountain Pine Beetle Steering Committee was established by the two involved Federal governments. Co-chairmen appointed were Dave Graham (U.S.) and Ross Macdonald (Canada). Other members included Jack Thompson (U.S. Field Coordinator), Max McFadden (U.S. Research Representative), and Tom Sterner (Canadian Coordinator and Research Representative). The current co-chairmen are Gordon Miller (Canada) and Dave Graham (U.S.). The U.S. "Field Coordinator" position has been replaced by the Local Border Lodgepole Pine Management Coordination Group, currently chaired by John Hughes, USDA Forest Service, Missoula, Montana. The current U.S. Research Representative is Garland Mason, USDA Forest Service, Washington, DC.

As part of the followup to the Fairmont Hot Springs meeting, a joint Canada/U.S. "Executive Summary" of the situation was prepared and furnished to all participants as well as to all key forestry and political leaders. This 15-page document also included statistical and map appendix information showing recent infestation trends and current status by major political subdivisions, and an Action Plan developed in final form during a joint Canada/U.S. October 1982 meeting in Victoria, BC. This Action Plan provided the basis for carrying out a number of specific program goals and objectives in both countries.

One of the major outcomes of the Fairmont Hot Springs meeting was a general consensus that a major accelerated research effort (similar to the Canusa Spruce Budworm Program) was not needed, although some significant research needs were identified. The most urgent program needs identified were: (1) to get agreement on what is really known about the mountain pine beetle and its interactions with lodgepole pine, and (2) to aggressively implement that knowledge in such a way so as to significantly reduce current and future losses in a timely manner.

This was all done in full realization that additional funding would probably not be forthcoming. However, part of the rationale behind the development of the Executive Summary was to provide all key decision makers with enough of the most significant information so that rearranging of current and future funding priorities could be considered. In the U.S., copies went to key congressional members, Senate Committee on Agriculture, House Committee on Interior and Insular Affairs, and both appropriation committees. Similar contacts were made with Cabinet Members in Canada. Except for some polite acknowledgments, there was no significant positive Federal response to the funding needs identified. However, control activities were eventually accelerated considerably, particularly in Alberta and British Columbia.

During the development of the Executive Summary, a number of meetings involving most of the key mountain pine beetle/lodgepole pine scientists in both countries were held. One of these, held in Bend, Oregon, on September 20-24, 1982, included a field trip to view demonstration areas showing dramatic differences in the severity of mountain pine beetle tree-killing between thinned and unthinned stands, many of which were mature (120 years plus). During this meeting, considerable effort was also spent jointly developing a "Statement of Facts" that attempted to more clearly define the "state-of-the-art," and management practices that could be currently

recommended to reduce mountain pine beetle losses. Copies of this document, which was subsequently refined in the U.S. through further exchanges with all scientists and practitioners involved, were circulated to all lodgepole pine area managers and practitioners.

Several meetings were also held during this same general time period to develop specific tasks and further refine responsibilities for accomplishing each Action Plan Item. The wrap-up Canada/U.S. work plan agreement meeting was held in Portland, Oregon, April 19-22, 1983.

Final approved work plans, including specific tasks and assignments, were provided on June 23, 1983, to all responsible units in the U.S. and shortly thereafter in Canada. One of the identified tasks was to develop periodic accomplishment reports showing progress and highlighting future needs. The first of these, which included a complete primary mountain pine beetle contact list and progress through 1983, was distributed in 1984. Progress Report No. 2, adding 1984 accomplishments, was distributed in 1985.

Much has been accomplished--most of it without additional funding. Accomplishments to date are summarized very well in the two Progress Reports and in the 1987 revised Work Plan.

PROGRAM REVIEW

A complete review of the program was carried out in 1985-1986. Each Action Plan Item, and the original tasks developed to accomplish each one, was reassessed in both countries in terms of progress made to date, current applicability, additional needs, and current funding requirements. The revised work plan was provided to all interested parties, including appropriate administrators and Congressional and Cabinet members in May 1987, as a revised "Canada/U.S. Mountain Pine Beetle Program/Work Plan--October 1986." The progress to date was noted in this revised Work Plan, and it serves as Progress Report No. 3. Separate progress reports covering 1985-1986 accomplishments were not published.

The Work Plan was recently revised again this year to update recent personnel changes, clarify some of the task assignments, and to reach agreement on priorities for whatever new funding may be made available. This latest revision was developed during a meeting with United States participants in Salt Lake City on December 3-4, 1987, and through a series of followup communcations with Canadian participants. Copies of this revision, which includes an up-date on accomplishments to date, were recently provided to all interested parties.

ACCOMPLISHMENTS

Program accomplishments to date highlight a broad spectrum of successful cooperative activities between Canadian and U.S. scientists and administrators. Some of the more significant accomplishments include:

1. Conducted Fairmont Hot Springs state-of-the-art meeting in Canada. Meeting initiated the development of a number of special coordination mechanisms and agreement on management strategies that could be immediately and effectively used to reduce future MPB resource damage.

2. Established a joint local border committee to ensure coordination and information exchange on MPB and lodgepole pine management among Canadian and U.S. resource managers with common administrative area boundaries.

3. Completed two up-to-date publications outlining recommended strategies for reducing resource losses under a variety of stand and MPB outbreak situations. For Canada: "Suppression of Mountain Pine Beetle in Lodgepole Pine Forests," McMullen et al, 1986. For U.S.: "Integrating Management Strategies for the Mountain Pine Beetle with Multiple Resource Management of Lodgepole Pine Forestry," McGregor and Cole, 1985 (replaces the 1977 INT General Technical Report-36).

4. Conducted Smithers, BC, May 1985 Symposium. A state-of-the-art meeting hosted by British Columbia Forest Service, Canada--somewhat similar to this symposium.

5. Published an inventory, description, and result highlights of existing MPB/LPP silvicultural studies and demonstration areas.

6. Developed INFORMS and expert system shell that employs artificial intelligence and integrates existing MPB/LPP data bases into a Geographic Information System (GIS).

7. Evaluated a number of lodgepole pine hazard rating systems to determine need and usefulness.

8. Coordinated the evaluation and registration of semiochemicals for manipulating mountain pine beetle populations in the U.S.

FUTURE

We believe this program will continue to receive top-level support in the years ahead in both countries. We plan to continue progress on this program with or without additional funding. We know the efforts being made, including the many innovative ways being used to accomplish most of the identified high-priority tasks without additional funding, are sincerely appreciated by those that appropriate and allocate resources. As additional progress is made in the future, we can expect increasing administrative and political recognition and support. This is truly a cooperative effort supported by a lot of dedicated people in both countries. We hope to build on this spirit of cooperation as we move ahead with this program in the future.

MOUNTAIN PINE BEETLE STATUS--WESTERN UNITED STATES

Kenneth E. Gibson

ABSTRACT: Though many MPB outbreaks are declining westwide, more than 2.5 million acres of host type were infested in 1987. Infestation levels and trends for each Region are noted.

INTRODUCTION

There are few superlatives which have not been used to describe the extent and magnitude of mountain pine beetle (MPB) infestations in the West during the last 20 years. New, in response to management activities and host depletion, many infestations Westwide have died out. Others are on the decline. Still, MPB is far and away the most devastating forest insect in western North America.

Though the focus of this symposium is on MPB effects in lodgepole pine (LPP), beetles regularly infest and kill nearly any pine species--both native and introduced--within their range. In our Region--western Montana and northern Idaho--serious infestations are occurring in ponderosa pine. Past outbreaks have killed hundreds of thousands of western white and whitebark pines as well.

The biology and ecology of MPB and its hosts will be discussed in great detail during the course of this symposium. Suffice it to say, in an introductory manner, that the beetle and its hosts have lived in mutualistic relationships for longer than we have been recording outbreaks. Mountain pine beetle, LPP and stand-replacing fires became a very efficient cycle which resulted in LPP becoming one of the most expansive forest types on the continent. About a century ago, however, land managers adopted a perhaps too successful fire suppression program, and a few decades hence, foresters were left to comtemplate literally millions of acres of dead LPP!

Paper presented at the Symposium on the Management of Lodgepole Pine to Minimize Losses to the Mountain Pine Beetle, Kalispell, MT, July 12-14, 1988.

Kenneth E. Gibson is an Entomologist, Timber, Cooperative Forestry and Pest Management, Northern Region, Forest Service, U.S. Department of Agriculture, Missoula, MT.

As I mentioned earlier, recorded MPB outbreaks go back as far as do records. It is widely believed that the journals of Lewis and Clark referring to downfall and dead timber were documenting the effects of MPB. More recently, Jim Evenden, early Forest Service entomologist, began surveying and recording MPB infestations throughout the Intermountain west in the 1920's. Localized outbreaks of varying degrees of severity were observed from then until the late 1960's. It was about then that our success in controlling fires began to be manifest in large expanses of mature to overmature LPP. Beginning in LPP stands in Yellowstone National Park and forests in Utah, Idaho, and Montana, the beetle's effect on stand structure over the past 20 years is well documented. In the area encompassed by the Forest Service's Northern Region--Montana, northern Idaho, and Yellowstone National Park--it is estimated that more than 250 million LPP have been killed in the last 20 years.

CURRENT STATUS AND ANTICIPATED TREND

At last, infestations in our Region--and for the most part other Regions as well--are declining. Still, in 1987, more than 2.5 million acres were infested westwide. The following is a Region-by-Region description of MPB outbreak status and the anticipated trend of those outbreaks in the foreseeable future.

Northern Region (Montana, northern Idaho, Yellowstone National Park): The series of outbreaks which continued to build in our Region through the late 1970's reached their peak at more than 2.4 million acres in 1981. Since that time, though some Forests continue to harbor locally severe and occasionally increasing infestations, acres on which infested trees were observed have gradually declined. In 1987, the infested area was reduced to approximately 722,000 acres--which includes all species on all ownerships. That was significantly reduced from 943,000 acres in 1986. Infestations on the Bitterroot, Idaho Panhandle, Kootenai, Flathead, and Nez Perce National Forests are increasing in some localities. Regionwide, however, we expect a continued decreasing trend in 1988 and for the next several years.

Rocky Mountain Region (eastern Wyoming, South Dakota, Colorado): In 1987, MPB infestations were recorded on more than 58,000 acres. Estimated mortality totalled almost 110,000 trees--approximately 30 percent were lodgepole pine, the remainder ponderosa pine. In Colorado,

MPB infestations in LPP peaked in 1982. As a result of the High Country Integrated Pest Management Project, suppression projects have reduced tree losses significantly in the past 5 years. Elsewhere in Colorado, beetle-caused mortality in ponderosa pine stands remains high, but is decreasing. Lodgepole pine stands in Wyoming continue to experience MPB-caused losses but at declining rates since 1984. A MPB outbreak in ponderosa pine near Laramie Peak is increasing. In South Dakota, infestations in the Black Hills are static at about 3,800 acres infested.

Southwest Region (Arizona, New Mexico): Historically, MPB has reached outbreak proportions at irregular intervals in ponderosa pine stands in northern portions of the Region. Infestations typically last 3 to 20 years with little recurrence in the same areas. At the present time, beetle activity is limited to scattered ponderosa pine stands on the Carson National Forest and adjacent Taos Pueblo Indian Reservation. Covering approximately 1,200 acres, the infestation could increase to 5,000 acres over the next 5 years. To date, some 1,800 trees have been killed.

Intermountain Region (western Wyoming, Utah, southern Idaho, Nevada): Tree mortality attributed to MPB decreased markedly in 1987. In 1986, an estimated 1.5 million trees had been killed. In 1987, that total did not exceed 200,000. Much of that reduction was due to the collapse of a once massive infestation in LPP and ponderosa pine stands in northeastern Utah. Static to slightly increasing infestations were noted in southern Idaho on the Boise, Challis, and Sawtooth National Forests. In total for the Region, infestations were recorded on 36,000 acres in southern Idaho, 97,400 acres in Utah, and another 2,300 acres in western Wyoming. Few of those infestations are expected to increase in 1988.

Pacific Southwest Region (California): Mountain pine beetle outbreaks in California have not been historically significant. However, locally important infestations occur from time to time. A small outbreak in ponderosa pine was recorded near Willits in 1987, and an infestation in LPP extended to 20,000 acres in Yosemite National Park. That outbreak, believed related to a lodgepole needleminer infestation, is expected to decline in 1988.

Pacific Northwest Region (Oregon, Washington): In numbers of acres infested, the Pacific Northwest Region contains the most expansive MPB outbreaks in the United States. In 1987, approximately 1.6 million acres were still infested--down from 1.76 million acres in 1986. Forests in Oregon continued to experience the most losses with more than 1 million cubic feet volume killed on 1.4 million acres on the Deschutes, Fremont, and Winema National Forests. In Washington, most losses occurred on the Okanogan National Forest. Infestations are expected to remain static in southcentral Oregon and increase in northcentral Washington in 1988.

The largest infestation in the Region--on the Deschutes National Forest--is moving from LPP stands to second-growth ponderosa pine.

CONCLUSION

In summary, though many areas are still experiencing serious MPB outbreaks--and associated impacts on several resources--we believe we are in the final stages of the last of the "great" MPB outbreaks. Perhaps through continued research, efficient technology transfer, and the economic and political climate needed to implement sound silvicultural practices, at the next MPB/LPP symposium we will be able to report that the beetle problem has been effectively dealt with.

STATUS OF MOUNTAIN PINE BEETLE IN WESTERN CANADA, 1988

G.A. Van Sickle

ABSTRACT: Although again at generally endemic levels in Alberta, mountain pine beetle continues to be a major forest pest in British Columbia. The extent of the present infestation is described along with trends, a forecast, and control programs.

INTRODUCTION

The mountain pine beetle continues, as it has for the past decade, to be the most damaging forest insect in British Columbia. Populations in southwestern Alberta and Saskatchewan have returned to endemic levels. Mature lodgepole pine are by far the most commonly killed tree species, followed by western white pine, occasionally ponderosa pine, and other pines. The distribution of currently active infestations in western Canada is shown in figure 1.

Lodgepole pine is distributed throughout British Columbia and adjacent Alberta. In British Columbia, it covers more than 14 million ha and by volume comprises 15% of the provincial inventory, although in some areas it is much higher, reaching 50% in the Cariboo Forest Region. Lodgepole pine is now the second ranking species, comprising about 24% of the annual provincial harvest. It has not, however, always been a commercially sought species, accounting for less than 5% of the harvest in the 1960s and only 2% in 1955. Not surprisingly, then, a large proportion of this species is mature and overmature; by area, more than half is more than 80 years old and almost three-quarters is more than 60 years old. It is these older trees that have been most susceptible to attack.

Mountain pine beetle outbreaks have been recorded within British Columbia at irregular intervals since at least 1910. Particularly notable early infestations occurred in the Princeton, Okanagan Valley, and Lillooet areas, and:

- from 1930 to 1936 vast areas were infested in central British Columbia;
- from 1930 to 1943 large infestations included Kootenay, Yoho, and Banff national parks;
- from 1946 to 1965 infestations were around Babine Lake in northcentral British Columbia and in scattered western white pine stands on Vancouver Island; and,
- from 1972 to 1977 all mature pine in the Kleena Kleene Valley in west-central British Columbia were killed.

CURRENT OUTBREAK STATUS

The current province-wide outbreaks started during the early 1970's, culminating in 1984 when red trees (recent faders) were present over more than 482 000 ha in British Columbia (fig. 2). By 1987 the area and volume of pine killed had declined to the lowest level in 7 years. However, more than 8900 infestations are still active on more than 66 400 ha widely distributed from the international border to north of Prince Rupert (fig. 1). This is almost double the area burned by forest fires in British Columbia in 1987. The volume killed, about 3.0 million m^3 in 1987, represents about 16% of the lodgepole pine volume harvested annually in the province and many forest companies are operating solely in mountain pine beetle salvage areas. Since 1972 more than 204 million mature trees have been killed by mountain pine beetle in British Columbia.

In Alberta and Saskatchewan, populations have generally returned to endemic levels (Cerezke in press) after infestations in the early 1980's spread over 7750 ha mostly in Waterton Lakes National Park as well as the adjacent Castle River area and spot infestations occurred throughout the Porcupine and Cypress Hills (Anonymous 1986).

The decline in infestations is due in part to major control programs, to depletion of susceptible host material in many areas, and, to a large degree, to overwintering brood mortality mainly in central British Columbia and Alberta caused by early, below-normal temperatures in late 1984 and again in 1985. In the Cariboo Region, which in 1985 accounted for at least 65% of the province's infested area, minimum temperatures below -30°C in October and -45°C in December 1984 virtually eliminated beetle populations. Slower development influenced by the cool wet summers of 1983 and 1984 probably also made the populations more susceptible to the early cold snap.

Populations elsewhere were less affected. In 1987, mountain pine beetle remained active over 19 000 ha in the Kamloops Region and 23 100 ha in the Nelson Region, especially in the western districts, and declined to 1470 ha in the Vancouver Region. In the Prince Rupert Region there was a 25% increase

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Paper presented at the Symposium on the Management of Lodgepole Pine to Minimize Losses to the Mountain Pine Beetle, Kalispell, MT, July 12-14, 1988.

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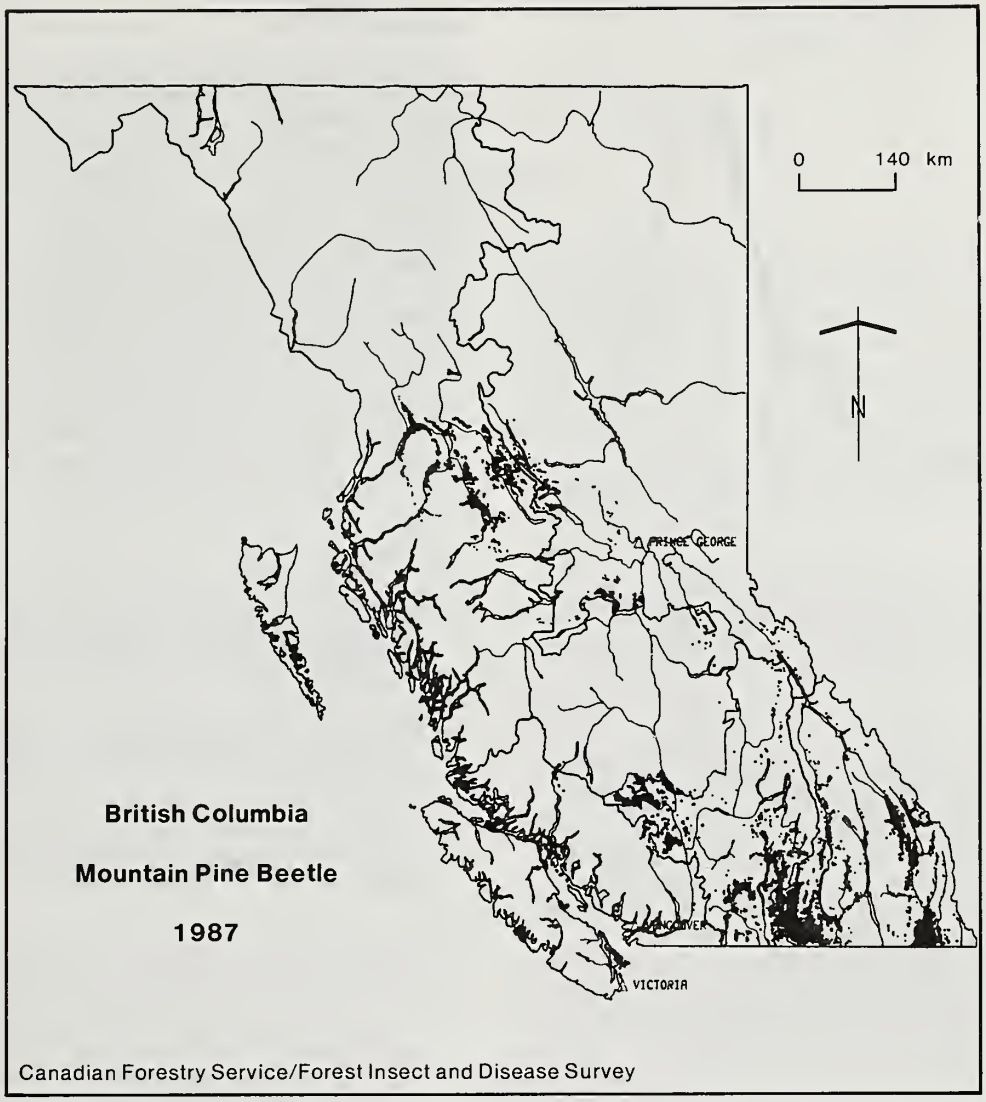

Figure 1--Areas where recent tree mortality due to mountain pine beetle was detected during aerial surveys in 1987.

to 18 600 ha and in the Prince George Region a threefold increase to 4300 ha, mostly northwest of Fort St. James. In the westernmost portion of the Cariboo Region, a new infestation developed over 500 ha, the first since the major winter kill.

Intensification and perhaps some spread is expected to become apparent in 1988. Based on stands cruised in the fall of 1987, the percentage of trees currently attacked averaged 20% (range 0 to 64%). This was an increase over 1986 levels and above the 12% average for red faders. New attacks were highest in the Prince Rupert and Prince George regions at 33% and 34%, respectively. Along the international border, new attacks averaged 13% in the Nelson Region and 6% in the Kamloops Region.

In southwestern Alberta, populations have declined to such a point that few recently killed lodgepole or limber pine were observed during aerial surveys. Placement of lures on 150 trees in the Kananaskis and Crowsnest Pass resulted in 47 attacked trees being cut and burned while a few remaining attacks were treated by removal of individual galleries. In the Cypress Hills, after 500 lures were deployed, only 20 fresh but unsuccessful attacks were recorded on the Alberta side and only five new attacks in three trees were recorded on the Saskatchewan side (Cerezke in press).

At the time of writing, overwintering brood survival and status in British Columbia is just being assessed. Overall, brood survival was good with more than 80% of the broods being healthy and vigorous."Reproductive trend values", (i.e., the ratio of overwintering progeny to parent beetles) are ranging from 0 to 11.2: values greater than 4.0 indicate increasing populations. In the Nelson Region, the ratio averaged 4.1, indicating a continuing but reduced population expected to attack trees in 1988 which will fade in 1989. Five areas had increasing populations and four areas

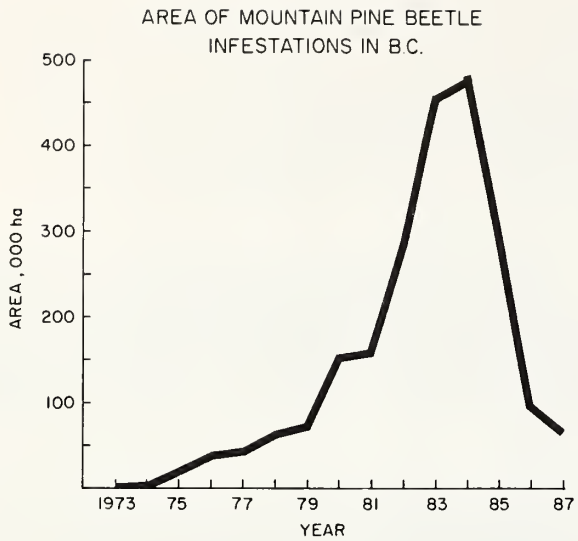

Figure 2--Area of new faders in mountain pine beetle infestations detected during annual aerial surveys from 1973 to 1987 in British Columbia.

were classified as static. In the Okanagan Valley of the Kamloops Region, seven of eight areas were increasing with an average value of 6.5. Stands to the west of the valley were mostly in a static class according to the bark beetle research group. In the Vancouver Region, values of 2.1 and 2.0 indicate a further slowing in an already declining population. Access difficulties in northern British Columbia reduced sampling, but in the western portion of the Prince Rupert Region values averaged 3.7 with four of nine stands classed as increasing, two static and three declining.

CONTROL PROGRAMS

To lessen the impact of mountain pine beetle on the sustainable annual harvest and to prevent its spread into vast uninfested areas, major bark beetle management programs were implemented in Alberta in 1980 and in British Columbia in 1984. In Alberta from 1980 to 1985, $6.2 million has been expended to encourage salvage and to detect and treat more than 107 000 infested lodgepole and limber pine trees (Anonymous 1986). In British Columbia, $37 million has been allocated in a planned 5-year, $50-million program started in 1984. This year about $8.1 million has been allocated to continue management activities including aerial photographic surveys, detection and delineation surveys, directed sanitation harvesting, single tree treatment projects, access construction, and use of aggregating pheromones (Hall personal communication).

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MOUNTAIN PINE BEETLE: BIOLOGY OVERVIEW

Les Safranyik

ABSTRACT: The general biology and ecology of the mountain pine beetle in lodgepole pine forests was reviewed with emphasis on insect-host interaction and causes of outbreaks. During endemic periods the beetles normally infest trees of low vigor such as injured, diseased or otherwise weakened trees and windfalls, usually in association with secondary bark beetles. Attack success in such trees tends to be high even at low attack densities but brood production is usually low. When the beetle populations switch from endemic to epidemic, the beetles infest proportionately more of the larger diameter trees in the stand. Many of these trees have thick phloem. Normally, such stands are more than 60 years old and the average diameter for trees 10 cm and larger is about 20 cm. Precisely which factors are responsible for triggering outbreaks is uncertain; however, all factors that would significantly reduce host resistance or increase the size of the beetle population above a threshold necessary for colonizing at least some of the large diameter trees with thick phloem could trigger outbreaks.

INTRODUCTION

The mountain pine beetle, Dendroctonus ponderosae Hopk., (Coleoptera: Scolytidae), a native insect in the pine forests of western North America, has been referred to as the most destructive bark beetle (Wood 1963). In areas where the beetle is common, it is the most important pest of mature lodgepole pine, Pinus contorta var. latifolia Engelm. During endemic periods, populations are innocuous, and only a few scattered infested trees are to be found. However, during outbreaks, which occur at irregular intervals and may persist for periods of 5 to 20 years, more than 80% of the host trees with a DBH of 10 cm or more may be killed over large areas.

In recent years, the losses caused by the mountain pine beetle, particularly in lodgepole pine, have been devastating. In British Columbia, for example, losses resulting from the 1983 attacks alone were estimated at 41 million trees killed in infested areas totaling 482 000 ha (Wood and others 1985). In infested stands managed for commercial production, the value of losses during epidemics is usually considerably greater than that indicated by the volume loss because most mortality is among the larger diameter trees. Outbreaks usually affect management plans and may create marketing problems. Outbreaks change stand density, age and species composition of stands, the size distribution of pine, and aesthetic values. Outbreaks also increase fuel loading, and hasten succession to the climax forest type.

The objectives of this overview are to provide a brief account of the population biology of the beetle in lodgepole pine forests, to highlight key features, and to identify gaps in the knowledge as a background to the main theme of the symposium. For more detailed descriptions of the population biology of the mountain pine beetle the reader is referred to Amman and Cole (1983) and other publications cited in this paper.

BIONOMICS

Geographic Distribution and Host Trees

The mountain pine beetle occurs in forests from northern Mexico (latitude 31°N) to northwestern British Columbia (latitude 56°N) and from the Pacific Ocean east to the Black Hills of South Dakota. It occurs up to about 750 m near the northern limits and up to about 3650 m near the southern limits of the beetles' range (Safranyik 1978).

The main hosts are lodgepole pine, ponderosa pine (P. ponderosa Laws.), western white pine (P. monticola D. Don), and sugar pine (P. lambertiana Douglas) (Amman 1978). This list of principal hosts is based on the commercial impact and intensity of epidemics. Other species of pine, including several exotic species within the range of the beetle, are infested and killed. Some non-host trees (e.g., Picea) are occasionally attacked and killed, but populations are usually not maintained in such trees.

Life Cycle

In the optimal portion of its range, the mountain pine beetle normally completes one generation per year. Brood adults typically mature in July. Young beetles are dark brown to black, and range in length from 3.5 to 7.5 mm. In order to complete maturation, they feed on the inner bark and on spores of blue stain fungi and yeasts which line the walls of the pupal chambers. During

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maturation feeding the flight muscles increase in size (Reid 1958) and the mycangium (a special structure on the head) becomes charged with fungal spores, which ensures transport of the fungi to new trees (Safranyik and others 1975).

Ambient temperatures are instrumental in determining the onset of emergence, the length of the emergence period, diurnal rates of emergence, and flight activity. Emergence normally begins after several days of warm, dry weather, but there is no apparent relationship between the duration of such warm periods and the onset of emergence (Safranyik 1978). Emergence and flight start at about 16°C, and rates of emergence are reduced at temperatures greater than 30°C. Peak daily emergence normally occurs during a period of 2-3 hrs in mid-afternoon when the temperature exceeds 20°C. The median dates of annual emergence can vary by as much as 1 month, but normally vary by 10 days or less. The period of peak emergence normally lasts a week to 10 days, but can vary from a few days to 3 weeks.

Beetles that do not disperse from the stand in which they develop usually locate suitable host trees within 2 days of emergence, but are capable of searching for several days. In release-recapture experiments using marked beetles in central British Columbia, one beetle was trapped at a baited tree 11 days after release more than 1 km from the release site. In the absence of pheromones, beetles tend to disperse downwind, mainly below the canopy in the clear bole zone, and search upwind only after an attractive pheromone plume is encountered. Very little is known about beetle flight above the canopy (other than that it occurs), or about long-range dispersal. Collection of mountain pine beetles in high-elevation snowfields in eastern British Columbia, Alberta, Washington (Furniss and Furniss 1972), and circumstantial evidence from elsewhere in the United States (Evenden and others 1943), indicates that long-range dispersals occur during outbreaks and may be significant factors in the spread of epidemics.

Searching adult beetles usually select and attack living trees during late July or early August. Fresh felled trees or windfall may also be attacked. Searching beetles land at random on host and non-host trees, hence one of the dominant theories of host selection states that initial attack by the pioneer beetles occurs at random, as opposed to being directed by some stress-induced "primary attraction." There is evidence, however, that dispersing adults land preferentially on lodgepole pines suffering from injury or disease (Gara and others 1984). As the pioneer female beetles bore into the bark, they release semiochemicals which attract both sexes and result in the aggregation of beetles on the focus tree, and eventually to close-range redirection of responding beetles to nearby trees (Borden and others 1986). In lodgepole pine, the beetles are strongly oriented to large-diameter trees. Vision is believed to play a key role in locating the host (Shepherd 1966). In addition to semiochemicals, physical and physiological host factors and beetle population size are thought to be important determinants of the density and distribution of attacks on the bole. On individual trees, mass attacks are normally completed within 1-2 days.

During gallery establishment, the beetles carry spores of the blue stain fungi, yeasts, and bacteria. These spores slough off along the walls of the galleries and grow in the living tissues. Although the roles of these organisms are not completely known, the blue stain fungi quickly invade and kill live cells, thereby preventing them from producing resin, which is the main defense of the tree against invasion by the beetle-microorganism complex. Blue stain fungi also effect a rapid reduction of moisture in the sapwood.

The female beetle bores through the bark and constructs an egg gallery averaging 25-30 cm in length in the phloem parallel to the grain. Mating takes place in the lower end of the egg gallery. The male often leaves after mating. The female plugs the gallery entrance and packs the lower end with boring dust. Usually 60-80 eggs, about 2 per cm, are laid singly in niches cut into the sides of the gallery. The eggs usually hatch in 1-2 weeks and the larvae feed in the phloem, roughly at right angles to the gallery. The larvae normally become dormant in late October or November and begin feeding again in April. Pupation takes place during mid to late spring and development is completed during late June to mid July.

There are exceptions to the 1-year cycle described above, and they depend primarily upon climate and weather (Safranyik 1985). The most common exceptions occur when many parent beetles establish two broods in a single warm, dry year, or in very cool years or at high elevations and latitudes where a proportion of the brood may require more than 1 year to complete development.

Brood Survival

Systematic studies of the nature and effect of factors affecting brood survival within and among trees have only been done on high endemic, epidemic, and postepidemic populations of the mountain pine beetle. Consequently, we have a poor understanding of brood survival and mortality factors in endemic populations.

It is generally believed that the same factors of mortality operate in both endemic and epidemic populations; however, the relative impact of some of these factors on brood survival, alone or in interaction with other factors, is considerably different at the two population states. For example, during endemic periods, often due to the low rates of attack, low attack densities, and perhaps also because of higher tree resistance, much higher proportions of unsuccessful attacks and higher brood mortality can occur than during epidemic periods.

Several life table studies from the United States (Amman and Cole 1981) suggest that during epidemics none of the natural, within-tree mortality factors investigated (competition,

predators and parasites, pathogens, drying of the bark, and resinosis) regulate beetle populations; survival of beetles at these times is more closely related to tree diameter and phloem thickness than any other factor. Reid (1963), based on population studies of a small infestation in southeastern British Columbia, found that tree diameter was the most important factor determining beetle survival.

The life table studies corroborated previous work (Cole 1974, 1975) showing that in areas where mountain pine beetle has mainly a 1-year life cycle, winter temperatures and drying of the phloem are the two most important causes of within-tree mortality and their effects are inversely related to tree diameter. With the exception of the predaceous fly, Medetera, beetle mortality resulting from predators, parasites, disease and resinosis was considerably less than that recorded for temperature and bark drying; Medetera showed a density dependent response over time. Reid (1963) too showed the importance of low temperature and subcortical moisture for affecting brood survival within trees, but he also found competition (in terms of egg gallery density) and resinosis to be important factors.

In general, mortality factors that are most important during the 1-year life cycle cause similar levels of mortality when more than 1 year is required to complete a generation (Schmitz 1985). However, at higher elevations and northern latitudes, cool temperatures that delay development and increase winter mortality replace food (phloem thickness) as the main factor limiting population survival.

In the life table studies referred to above, about one-half of total mortality was caused by unknown factors. This is a rather typical result for bark beetle population studies in general and emphasizes the need for better knowledge of mortality factors and improved experimental procedures.

Mortality within trees is just one component of total mortality in each bark beetle generation. We have inadequate knowledge of mortality among emerged beetles during the dispersal-host finding phase. This mortality may be 60% or higher, depending on population levels in relation to host availability, weather, and other factors, and may be one of the key factors limiting population growth at endemic and postepidemic levels.

Epidemiology

Under endemic conditions the mountain pine beetle often infests trees of poor vigor which were first infested by secondary bark beetles such as Ips and Pityophthorus spp. (Amman 1978), or attack injured, diseased, defoliated or otherwise stressed trees, and windfalls. High endemic or incipient infestations, which characteristically kill small groups of trees, are often found in draws, gullies, along edges of stand openings, or in areas subjected to soil compaction or wide fluctuations in the water table (Safranyik and others 1974). These incipient infestations may develop into outbreaks in a few years or may continue, especially in lodgepole pine stands of poor site quality, until most of the large-diameter pine component are killed. A major exception to this pattern of outbreak development occurs when local populations are augmented by the influx of large numbers of beetles from nearby infested stands, especially those at lower elevations. In this case, low populations and damage levels in a given year in some areas could be followed by epidemic infestations in the following years.

Outbreaks in lodgepole pine last from 3 to 20 years, range in size from a few hectares to hundreds of square kilometers, and invariably deplete the large-diameter component of stands (Safranyik and others 1974). In areas with cooler climates, such as areas at high elevations and northern latitudes, the intensification and spread of outbreaks tend to be less but outbreaks may persist longer than in areas within the beetle's optimum range.

During mountain pine beetle epidemics, large populations of secondary bark beetles usually build up in the tops and other sections of the bole and large branches of trees killed by mountain pine beetle. Following the decline of mountain pine beetle epidemics, these secondary bark beetles, especially Ips and Pityogenes, attack and kill some of the remaining pines, mostly in the smaller diameter classes. Occasionally, tree killing can be extensive, but it rarely lasts longer than 1-2 years.

CAUSES OF OUTBREAKS

Although a great deal is known about the population ecology of the mountain pine beetle in lodgepole pine, our knowledge of how the transition from endemic to epidemic populations occurs is uncertain.

In natural lodgepole pine stands, outbreaks usually occur when the average age of the pine component is about 80 years or more and the average diameter of the pine greater than 10 cm is about 20 cm. Outbreaks usually develop in areas that are climatically most suited for beetle development and survival. Proportionately more of the large diameter trees are killed (Hopping and Beall 1948; Cole and Amman 1969). Brood production from infested trees is directly proportional to the thickness of the inner bark (Amman 1972; Berryman 1976).

Resin production in response to invasion of the beetle-blue stain fungi complex is a measure of host resistance to attack (Reid and others 1967), and is normally greatest in the largest diameter, fastest growing trees at a given age and site quality (Shrimpton 1973). At the stand level, resistance tends to be the greatest near the culmination of current annual increment (between 40 to 60 years, depending on site quality) and declines rapidly with increasing age (Safranyik and others 1975). The culmination of stand resistance corresponds to the attainment of the greatest basal area, biomass, and nitrogen

accumulation in lodgepole pine ecosystems following a stand-replacing fire (Fahey and Knight 1986).

As average phloem thickness is related to basal area growth during the preceding 6- to 10-year period (Shrimpton and Thomson 1985), both phloem thickness and resinosis are directly related to tree or stand vigor. Consequently, there is an apparent paradox in our information: if epidemic infestations can only be maintained in large diameter trees with thick phloem and if these are also the trees that tend to be the most resistant, how then can the switch from endemic to epidemic occur at all? We do not have definite answers, but a plausible explanation is as follows: It is generally acknowledged that the degree of host response to attack and host suitability for mountain pine beetle reproduction is dependent on beetle numbers, at least at low population levels (Raffa and Berryman 1983). Consequently, as the beetle population increases, trees of higher resistance become available for colonization and outbreaks are triggered when a threshold of beetle numbers is attained that can successfully colonize large diameter trees with thick phloem (Berryman 1978). This beetle population threshold may be exceeded in stands suffering from temporary weakening such as that caused by drought or defoliation, or from decline of tree vigor following attainment of physiological maturity (reduction of phloem thickness follows growth reduction with considerable time lag). The threshold may also be exceeded when endemic subpopulations within scattered weakened trees are close enough to concentrate attacks on one tree or a small group of trees of medium to large diameter and moderate to thick phloem (Amman 1978), or when large numbers of beetles disperse into a stand from other infestations. If weather conditions are unfavorable for the beetle, these incipient infestations will decline and several years may elapse before conditions for the development of an epidemic occur again.

Better understanding of outbreak development is of great practical importance for development of better systems for predicting outbreak hazard, and for development of more effective methods of management to reduce losses. More knowledge is urgently needed on population dynamics in the endemic state, qualitative differences between endemic and epidemic beetle populations, primary attraction and chemical communication, the role of host tree injury and stress factors in triggering outbreaks, and the role of dispersal in the spread of epidemics.

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LODGEPOLE PINE: AN ECOLOGICAL OPPORTUNIST

Wyman C. Schmidt

ABSTRACT: Lodgepole pine is a persistent opportunist found in a remarkable variety of ecological zones in the U.S. and Canadian mountain West. Classification systems for biogeoclimatic zones and ecological habitat types populated by lodgepole pine are described. Information that relates habitat types where lodgepole is found with mountain pine beetle susceptibility is included.

INTRODUCTION

This is a story about an ecological opportunist of the Mountain West--lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.). The story actually began eons ago, but it repeats itself time and time again in an ecological clocklike cycle. If you could collapse 100-200 years into a 24-hour time period it would go like:

Time	Event
2400 Midnight	Fire
0000 - 0200	Lodgepole pine regeneration
0200 - 1600	Stand development
1600 - 2000	Bark beetle (*Dendroctonus ponderosae* Hopk.) epidemic
2000 - 2400	Fuel buildup
2400	Fire
0000 - 0200	Lodgepole pine regeneration
0200 - 1600	Stand development
1600 - 2000	Bark beetle epidemic
2000 - 2400	Fuel buildup
2400	Fire
0000 - 0200	Lodgepole pine regeneration
0200 - 1600	Stand development
1600 - 2000	Bark beetle epidemic
2000 - 2400	Fuel buildup
2400	Fire
	(and on and on infinitely)

Now, if you throw in an occasional ice age in western United States and Canada to give it a little variety, you have the "Rest of the Story" of long-term succession of ecosystems through time in lodgepole pine forests.

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Lodgepole pine goes through this ecological cycle on a large proportion of its domain unaccompanied by its conifer and broadleaf associate species. However, in many areas lodgepole pine has a large variety of companion species that have similar silvical requirements and fall into the same clocklike succession. These companions usually slow or accelerate the successional process.

So the story gets somewhat more complicated then first indicated. But to really complicate it put man into the equation. He does not like fire; he does not like beetles; he would like to utilize the woody fuels that just burn up in wildfires; he would like to regenerate trees faster than nature does alone; he would like to grow bigger trees faster. He wants lodgepole pine forests to look esthetically pleasing throughout this whole process (even though nature itself can't always accomplish this); he wants the forests to be desirable for wildlife and water production, and on and on.

Most managers want to be able to predict and regulate what will happen in a somewhat more limited time and space than described earlier. Since some of these effects will be covered in other papers of this symposium, this paper will focus on the ecological aspects of lodgepole pine forests that currently occupy the vast slopes and valleys of the Mountain West.

GENERAL ECOLOGICAL PERSPECTIVES

Why call lodgepole pine an opportunist? Lodgepole pine grows in an extremely wide range of ecological conditions: from low to high elevations, from relatively dry to wet conditions, from warm to cold, on most every soil condition found in the West, has two modes of seed dispersal, has rapid juvenile growth to start it out in a dominant position in the stand, and has other attributes it needs to truly make it an aggressive opportunist (Schmidt 1982).

But lodgepole pine pays the price for some of its opportunistic ways. It is short-lived compared to most of its associate species. It is highly susceptible to bark beetles at a relatively early age; the largest lodgepole pines in the stand are the favored targets for the bark beetle. It is subject to diseases that can debilitate it. But, overall, this versatile species holds great potential for intensive management over vast areas of the West (Schmidt and Alexander 1984).

The ecology of lodgepole pine forests is made up of a whole spectrum of variables such as fire frequency, elevation, topographic position, associated vegetation, edaphic factors, stand density and homogeneity, site quality, geographic location, insects, and disease. Mix all of these and a few other as yet unidentified factors and you have the beginnings of an equation that helps describe lodgepole pine forest ecology. Combine this information with classifications such as forest cover type, ecological habitat type, biogeoclimatic zone, or some other classification and you begin to provide a recipe that helps describe and communicate what is up at the head of Elk Creek, or management zone B, or stand number 28, or T25NR16W, Sec. 6, or other locations with similar designations.

Ecologists have had a long history of disagreements on terminology and how to describe and classify vegetation and site. Some classifications are based on the vegetation presently occupying the site such as cover types (Eyre 1980); others are based on the potential or climax vegetation that can be expected in the long term on the site (Daubenmire 1966).

However, most ecologists do agree on the concept of succession, the progressive development of ecosystems through time, and how climax and seral vegetation fit into that mold. That agreement simplifies the discussion of lodgepole pine. With minor exceptions, lodgepole pine is a seral species with remarkable ecological amplitude. Lodgepole pine is highly intolerant of shade and although some seedlings may become established under a forest canopy they seldom grow to maturity unless released. As a result, most lodgepole pine forests are essentially even-aged and relatively homogeneous. Barring any major disruptive event, such as fire, lodgepole pine is usually succeeded by more shade-tolerant species such as Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.). This succession proceeds at different rates, moving relatively fast on the lower elevation mesic sites and particularly slow in high-elevation forests such as those extensive stands along the Continental Divide area of Montana (Lotan and Perry 1983).

Pfister and Daubenmire (1975) described what they felt were four basic successional roles for lodgepole pine.

1. Minor seral - lodgepole pine is a minor component in young, even-aged, mixed species stands which are replaced by more shade-tolerant associates in 50 to 200 years. The most rapid transition occurs on the more mesic sites.

2. Dominant seral - lodgepole pine is the dominant cover type of even-aged stands. Vigorous understory shade-tolerant trees will replace the lodgepole in 100 to 200 years.

3. Persistent - lodgepole pine forms the dominant cover type of even-aged stands with little evidence of replacement by shade-tolerant species. This usually occurs because other species are not present due to inadequate seed sources or the sites are poorly suited to other species.

4. Climax - lodgepole pine is the only species capable of growing on some sites and it perpetuates itself. This is most commonly found on sites where soils hold only limited moisture and sometimes where frost pockets occur. These types of site conditions usually result in uneven-aged stands that are climax in character (Franklin and Dyrness 1973). They are often droughty edaphic situations such as the obsidian sands in the Yellowstone Park area and similar conditions in central Oregon.

ECOLOGICAL CLASSIFICATIONS

One of the first approaches to understanding any kind of organism or groups of organisms is to separate them into some type of class whether by composition, reproductive habit, growth habit, color, size, age, or other criteria. Separation into classes permits orderly description that can then be made to provide a common mode of communication.

Although very complex in most cases, classification systems that include lodgepole pine as major and minor components have been developed for ecosystems in both the United States and Canada. As more and more information is being developed for the various ecological classifications a greater amount of predictability should be forthcoming.

Terminology differences can be a stumbling block in utilizing classification methods. The plant association, as defined by Daubenmire and Daubenmire (1968), is the aggregation of all climax forests that have essentially the same dominant species and biotic potential. Habitat types, as developed for the northern and central Rockies of the United States, and plant associations in the Pacific Northwest, illustrate this classification concept. Those habitat types and associations that have the same potential dominant climax species form what are called series. The term community type is used to name a type of recurring vegetation where climax has not been verified (Daubenmire 1976).

Table 1--Ecological amplitude of lodgepole pine in various geographic areas (from Lotan and Perry 1983 and adapted from Pfister and Daubenmire 1975)

Geographic area	Occurrence of lodgepole pine
Northern Idaho and eastern Washington	12 of 22 forest habitat types
Boise and Payette National Forests, ID	25 of 33 forest habitat types
Sawtooth Range to Pioneer Mountains, ID	9 of 14 forest community types
Wind River Mountains, WY	4 of 5 forest habitat types
Medicine Bow Mountains, WY	2 of 5 forest habitat types
Western Montana	18 of 30 forest habitat types
Central and eastern Montana	30 of 45 forest habitat types
Subalpine forests, Utah	2 of 4 forest habitat types
East slope of the Front Range, Colorado	6 of 16 sample stands
Colorado Front Range, CO	3 of 3 forest zones
Ochoco National Forest, OR	3 of 7 forest associations
Pumice region of central Oregon	6 of 6 forest communities
Subalpine forests, southern Washington	4 of 15 forest habitat types
British Columbia	9 of 11 biogeoclimatic zones
Similkameen Valley, BC	3 of 7 forest habitat types
Douglas-fir zone of interior British Columbia	4 of 4 forest community types
South-central interior, British Columbia	10 of 14 site types
Rocky Mountains, AB	16 of 23 forest habitat types

Excellent summaries have recently been prepared for various aspects of lodgepole pine ecology and management (Lotan and Perry 1983; McGregor and Cole 1985; Pojar 1985; Volland 1985). To get a better perspective on the ecological amplitude of lodgepole pine, Lotan and Perry (1983) summarized information that had been developed about the occurrence of lodgepole pine in the various geographic areas throughout its range (table 1). Eight different types of vegetation classifications comprised the summary. As noted in their summary, lodgepole pine occurs in over 60 percent of the vegetation classes developed for the geographic areas they describe.

Volland (1985) noted in his summary on the ecological classification of lodgepole pine in the United States that lodgepole pine has been described as a seral species in 114 associations and 15 different tree series. He felt that lodgepole pine was a persistent seral member in another 21 plant communities and a climax species in 33 associations. He graciously provided a detailed listing of all these series and communities as well as the reference information.

Pojar (1985) summarized the ecological classifications used for lodgepole pine in Canada. Although other systems are used in some areas, by far the most commonly used ecological classification in the range of lodgepole pine in Canada is the biogeoclimatic ecosystem classification. This classification results from a synthesis of climate, vegetation, and soil data. It was developed primarily by Krajina and his students (1965, 1969) and has been used for much of British Columbia and Alberta. It is being developed as a multi-level hierarchy with emphases on ecosystem and zonal levels.

Ecosystem classes are based mostly on small areas relatively homogeneous in vegetation and soils while biogeoclimatic classes are based mostly on regional climate, vegetation, and soils. In simple terms, the biogeoclimatic zones are quite broad and the ecosystem categories are relatively narrow.

Alberta and British Columbia forests are divided into nearly 20 of these biogeoclimatic zones, and lodgepole pine occurs in all but three of the zones. Pojar (1985) illustrated the ecological amplitude of lodgepole pine with a table of occurrence in several different biogeoclimatic zones as follows:

Biogeoclimatic zone	Occurrence of lodgepole pine
Montane spruce	24 of 29
Sub-boreal spruce	64 of 106
Engelmann spruce-subalpine fir	44 of 80
Boreal white and black spruce	12 of 29
Interior cedar-hemlock	37 of 92
Interior Douglas-fir	29 of 83

Table 2--Relationship of bark beetle infestations to habitat type and elevation in S.E. Idaho and N.W. Wyoming (adapted from Roe and Amman 1970)

Habitat type	Elevational range of stands (feet)	Stands infested with bark beetles (percent)
Abies lasiocarpa/ Vaccinium scoparium (cold and moist)	6,500-8,500	44
Abies lasiocarpa/ Pachistima myrsinites (warm and moist)	6,700-7,800	92
Pseudotsuga menziesii/ Calamagrostis rubescens (warm and dry)	6,000-7,800	64

ECOLOGICAL CLASSES AND THE BEETLE

It would be great to be able to say that we know which eco-classes containing lodgepole pine are most, least, or moderately susceptible to mountain pine beetle attack, how much these attacks would impact lodgepole pine stands, when this would occur, and what we can do to help alleviate the problem. Unfortunately we are not there yet, and the information to date has been difficult to interpret, but we do have some hints about the relationship of bark beetle activities in different ecological classes.

One of the first significant attempts at relating beetle activity to ecological habitat types was made by Roe and Amman (1970). They concluded that active infestations in southeast Idaho and northwestern Wyoming varied by habitat type with the heaviest infestations in the most mesic habitat type--Abies lasiocarpa/Pachistima myrsinites--as shown in table 2. However, this was complicated to some extent by elevational overlaps between habitat types. Elevation has always been regarded as a significant factor in bark beetle infestations, with the very high elevations less hospitable to the bark beetle. The Roe and Amman study area was limited geographically and, as shown in table 2, habitat types in the study area overlapped in their elevational distribution. Both the limited geographical area and elevational overlap tend to add credence to the ecological habitat relationship to beetle activity.

McGregor (1978) evaluated beetle mortality of lodgepole pine in relation to elevation and ecological habitat types on what he classified as dry mountain slopes and moist mountain slopes in Montana. He concluded there were mortality differences, in terms of basal area of trees ≧ 8 inches DBH, between habitat types on the dry slopes. But, mortality varied only from 40 to 42 percent on the three lower elevation habitat types--Abies lasiocarpa/Vaccinium scoparium - Calamagrostis rubescens, the Abies lasiocarpa/Calamagrostis rubescens, and the Pseudotsuga menziesii/Calamagrostis rubescens-Calamagrostis rubescens. Meanwhile, the higher elevation (about 8,000 ft) Abies lasiocarpa/Vaccinium scoparium-Vaccinium scoparium habitat type showed 25 percent mortality. The moist slopes showed greater differences in beetle mortality within the same general elevation zone but again, the two lower elevation habitat types Picea/Linneae borealis and Abies lasiocarpa/Linneae borealis had about twice the mortality of the upper elevation habitat types with 40 percent mortality of trees ≧ 8 inches DBH. Mortality upslope was 20 percent on the Abies lasiocarpa/Vaccinium globulare and 13 percent on the Abies lasiocarpa/Alnus sinuata habitat types.

Unfortunately, most analyses of these types of data are not inclusive enough to permit separation of the effects of individual site and stand variables such as elevation, slope, aspect, host/non-host ratios, age, and stand density from that of ecological habitat type or classes as such.

An indirect method of relating potential mountain pine beetle damage to ecological habitat type is through the beetle's food source, the phloem of lodgepole pine. Cole's (1973) analyses of phloem thickness showed ecological habitat type groups as the second most important variable, after basal area increment, in predicting phloem thickness. His statistical evaluations indicated Pseudotsuga menziesii/Physocarpus malvaceus, Pseudotsuga menziesii/ Symphoricarpos albus, and Abies lasiocarpa/Pachistima myrsinites could be grouped to predict phloem thickness and that the combination of Abies lasiocarpa/Vaccinium scoparium and Pseudotsuga menziesii/Calamagrostis rubescens could also be grouped together for phloem predictions.

McGregor and Cole (1985) examined integrated strategies for dealing with mountain pine beetle problems where multiple resources were at stake in lodgepole pine forests. In those guidelines, Pfister and Cole (1985) described the successional role of lodgepole pine relative to different habitat types and assigned lodgepole pine to four successional roles: usually minor seral, often dominant seral, usually dominant seral, and persistent climax (table 3).

Cole (1985) further elaborated on the ecological relationships, using habitat types as a framework, and described the character and number of habitat types and their successional roles for the Gallatin and Flathead National Forests in Montana. When combined with stand characteristics of basal area and size classes, the combined information provides a good tool for examining potential management opportunities and problems such as bark beetles.

A current study by Cole (1983) should start to provide more definitive answers about the relationship of ecological habitat type to bark beetle activity in intermediate age stands. This study addresses the relationship of bark beetles to managed stands and how these interact with the variables of age, stand, and site factors within an ecological habitat type matrix.

DISCUSSION

There is a current adage that says "We've come a long way baby." We have. Much has been accomplished in learning the ecological facts about lodgepole pine forests throughout its range in the United States and Canada, and there are several recent publications that do a good job summarizing this information. In spite of the fact that not everyone agrees on ecological terminology, most everyone agrees that ecological classifications are an extremely useful working tool in describing and communicating about forest types.

Perhaps our biggest challenge in effectively utilizing classifications both north and south of the U.S./Canada border lies in being able to tie other factors to the zones or classes such as tree growth, water production potentials, wildlife habitat, esthetic values, potential disease and insect problems, and the like. Some of these factors will cross many of the strata in the classifications, others may be restricted to one strata or part of a strata. It is when we can determine how a particular factor behaves within or between strata of the vegetative classifications that we will fully realize the value of the ecological classifications.

Unfortunately, we have a fair distance to go before we have the relationship of bark beetles and ecological habitat type or other forest and land classifications deciphered. There are, however, some things that we can say with some degree of confidence, such as:

1. Mountain pine beetle infestations can easily cross the boundaries of most of the ecological strata of currently used classifications--they are not a respector of ecological boundaries formed by classifying vegetation or other components.

2. Groupings of vegetative or biogeoclimatic zones or perhaps series may prove more realistic for delineating and predicting beetle activities. Beetle zones appear to be much broader than the present vegetative classes. There are enough hints already to proceed with efforts to quantify some of these relationships.

3. Bark beetles appear to be most damaging in the mid-range of water and temperature gradients of lodgepole pine forests.

4. A better understanding of the successional patterns on the large number of ecological zones or habitats in which lodgepole pine occurs would help considerably in understanding the beetle/stand/site relationships.

5. Greater uniformity in ecologists' terminology would enhance the opportunity for communication in relating beetle activity to ecological zones or features.

6. Lodgepole pine and mountain pine beetles have co-existed successfully for eons and both qualify as being opportunists. They are so closely linked ecologically that minor disruptions in the natural succession can likely be expected to significantly affect the other species positively or negatively. Learning to capitalize on this feature is a promising management tool.

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Table 3--Habitat types where lodgepole pine is a component, by successional roles (adapted from McGregor and Cole 1985)

USUALLY MINOR SERAL		
Montana	Northern Idaho	Northwestern Montana
Warm-dry	Cool-moist	Cold-moist
Douglas-fir/ snowberry	Grand fir/ queencup beadlily	Subalpine fir/ smooth wood-rush
Douglas-fir/ ninebark	Grand fir/ twinflower	Mountain hemlock/ menziesia
Subalpine fir/ virgin's bower	Western hemlock/ queencup beadlily	Mountain hemlock/ smooth wood-rush
	Western redcedar/ queencup beadlily	

OFTEN DOMINANT SERAL			
	Montana		Northern Idaho & Northwestern Montana
Warm-dry	Cool-moist	Cold-dry	Warm-moist
Douglas-fir/ twinflower	Spruce/ ninebark	Subalpine fir/ elk sedge	Subalpine fir/ queencup beadlily
Douglas-fir/ pinegrass		Subalpine fir/ whitebark pine/ grouse whortleberry	

USUALLY DOMINANT SERAL				
	Montana		Northern Idaho and Northwestern Montana	
Dry	Moist	Cold-moist	Cold-dry	Cold-moist
Douglas-fir/ common juniper	Douglas-fir/ Dwarf huckleberry	Subalpine fir/ bluepoint	Grand fir/ beargrass	Subalpine fir/ menziesia
Subalpine fir/ pinegrass	Spruce/ queencup beadlily	Subalpine fir/ twinflower	Douglas-fir/ blue huckleberry	Mountain hemlock/ beargrass
	Spruce/ sweetscented bedstraw	Subalpine fir/ grouse whortleberry	Subalpine fir/ beargrass	
	Spruce/twinflower			
	Spruce/ starry Solomon's seal			
	Spruce/ dwarf huckleberry			
	Subalpine fir/ blue huckleberry			
	Subalpine fir/ Sitka alder			
	Subalpine fir/ heartleaf arnica			
	Subalpine fir/ sweetscented bedstraw			

PERSISTENT CLIMAX	
Central and Eastern Montana	
Cold-dry	
Subalpine fir/dwarf huckleberry	Lodgepole pine/dwarf huckleberry
Lodgepole pine/twinflower	Lodgepole pine/pinegrass
Lodgepole pine/grouse whortleberry	Lodgepole pine/bitterbrush

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DETECTION AND SURVEY METHODS

FOR

MOUNTAIN PINE BEETLE

R. Ladd Livingston

Detection surveys for mountain pine beetle are generally conducted from the air. Usually this is done as part of an annual pest detection survey where newly infested spots are marked on a map for later reference. Due to the annual nature of these surveys, population trends can be followed. Computerized mapping and data summaries of the aerial sketch map information can greatly aid this detection and survey work.

As a new survey tool, semiochemicals are being used by the Canadian provinces of Alberta and Saskatchewan to monitor low level beetle populations and to attempt to detect increases of activity. Mountain pine beetle pheromones are being deployed as tree baits to provoke attacks on baited trees (Van Sickle 1988).

Once the location of a new outbreak is known, evaluations can be conducted to determine the need for follow-up action and to determine the type of action that might be required. Standard forest cruising techniques have been incorporated with computer programs to produce volume tables of standing green and pest-infested trees. Also, for outbreaks of the mountain pine beetle in lodgepole pine, this program will make predictions of 10-year losses and of residual stand volumes after the outbreak has subsided (Bousfield and others 1985).

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PRELIMINARY EVALUATION OF HAZARD AND RISK RATING VARIABLES FOR MOUNTAIN PINE BEETLE INFESTATIONS IN LODGEPOLE PINE STANDS

Gene D. Amman and John A. Anhold

ABSTRACT: Difficulty in deciding on the most appropriate from among the many methods available for assessing lodgepole pine stand hazard and risk to mountain pine beetle infestation prompted an evaluation of these methods as part of the Canada/United States Mountain Pine Beetle Program. As a first step, some of the variables used in hazard and risk rating methods were analyzed by multiple regression to determine those with which the percent tree mortality was most closely correlated. These variables were found to differ by geographic area. Preliminary results suggest that best results in predicting hazard or risk will be achieved on an individual stand basis, and that tree size (positively related to tree mortality) and stand density (negatively related to tree mortality) will be important variables in any hazard or risk rating system.

INTRODUCTION

Hazard and risk rating methods to assess infestation potential of mountain pine beetle (MPB) (*Dendroctonus ponderosae* Hopkins) in lodgepole pine (*Pinus contorta* Douglas) stands are important tools to help deal with the MPB problem. These methods are designed to help land managers identify stands in which MPB epidemics are most likely to erupt and how much loss of timber is likely to occur.

There are many hazard and risk rating methods for assessing mountain pine beetle infestations in lodgepole pine stands. This profusion of methods is confusing--users are uncertain which should be used. Few have been adequately tested in the geographic area where they were developed, much less in other geographic areas. Therefore, as part of the Canada/United States Mountain Pine Beetle Program, a test of the various hazard and risk rating methods was undertaken over the range of mountain pine beetle distribution in lodgepole pine. We report some preliminary results for the western United States. Terry Shore (these proceedings) reported those for western Canada.

The objectives were to determine (1) which of the hazard and risk rating methods does the best job for a given geographic area, and (2) if a different set of parameters would do a better job of predicting hazard and risk than those now in use. The objective of this paper is to examine factors that were most closely associated with lodgepole pine mortality caused by MPB. The objective of determining how well the various hazard and risk rating methods performed cannot be fully assessed until sampled stands are revisited and total tree mortality determined.

RISK AND HAZARD

The terms "hazard" and "risk" are often used synonymously. However, we will follow the definitions given by Waters (1985):

> "Hazard is determined by tree, stand, site, and climatic factors that basically influence the probabilities of tree mortality. For individual trees, this means tree qualities or characteristics that affect the likelihood of successful beetle attack, for example, age or size, vigor, location. For a stand or area, it refers to factors affecting the likelihood of an outbreak occurring in that stand or area, for example, species composition, age-size structure, density, soil type, precipitation, disturbance--or more gross measures such as habitat type, elevation, or landform.
>
> "Risk, on the other hand, is a function of beetle abundance and distribution. Regardless of inherent hazard, a significant number of beetles must be in the general proximity for tree mortality to occur. Thus, a high hazard tree or stand may exist for years--to harvest, perhaps--without being infested. Conversely, a low hazard tree or stand may be considered at high risk--and successfully attacked--if within the area of an ongoing outbreak."

Hazard to MPB infestation has been related to a number of tree, stand, site, and climatic factors. These differ by geographic area and include the following: tree age and d.b.h.; latitude and elevation (Amman and others 1977); tree d.b.h.; culmination of current and mean annual increment and weather (Safranyik and others 1974); periodic

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growth ratio (PGR)--current 5 years' radial growth divided by the previous 5 years' radial growth (Mahoney 1978); crown competition factor and percent lodgepole in a stand (SHR) (Schenk and others 1980); PGR divided by SHR and the percent basal area containing phloem 0.1 inch or thicker (Berryman 1978); quadratic mean diameter and number of growth rings in the last centimeter of radial growth (Stuart 1984); stand density index (SDI) (Anhold and Jenkins 1987); habitat type (Cole and McGregor 1983; McGregor 1978; Roe and Amman 1970); and growth efficiency (Waring and Pitman 1980; Waring and others 1980)--grams of stem wood produced per square meter of foliage, using sapwood area as a predictor of foliage area.

The resinous response of trees to inoculation of blue-staining fungi (Ceratocystis clavigera [Robinson-Jeffrey and Davidson] Upadhyay) (Raffa and Berryman 1982; Shrimpton 1973) also has been used as a measure of tree susceptibility to MPB infestation. Those trees having the greatest resinous response were considered least likely to be infested by MPB. However, in a field test of the method the tree response to fungal inoculation did not distinguish between susceptible and nonsusceptible trees to MPB infestation (Peterman 1977). The fungal inoculation method was not included in this test because it is quite time consuming.

Regardless of which hazard factors are used, beetle population size (risk) plays a very important role. An illustration of risk was given by Nebeker and Hodges (1983). In this illustration, trees with different abilities to withstand beetle infestation become susceptible to infestation, based on size of the beetle population. Until MPB infest trees suitable for good brood production--that is, trees of large diameter and thick phloem--an epidemic cannot start. Therefore, stands of lodgepole may contain all the elements for an epidemic of MPB, but because beetle numbers are low, an epidemic does not occur. When numbers are large, no tree is likely to be resistant to successful infestation.

Schmitz (in press) observed that during the endemic phase few MPB are present and are usually found in association with secondary bark beetles. These secondary bark beetles usually infest suppressed sapling or pole-size trees that are well below average in growth, have thin phloem, and are often partially girdled by porcupines. However, during an epidemic, the associates infest the tops of limbs of larger diameter trees killed by MPB the previous year. The secondary species usually overwinter in the adult stage in litter on the forest floor. They emerge during spring and infest trees soon after the snow melts. In contrast, the MPB emerge from late June to early September, depending on location. At endemic levels, only a few MPB emerge on any one day. Unless the time required to locate suitable trees to infest is minimized, a large proportion of such sparse populations is likely to succumb during dispersal. By utilizing trees already infested by other secondary scolytids, MPB dispersal losses are reduced. However, selection of trees that are already infested by secondary scolytids results in low MPB production because of small tree size, thin phloem, and infestation of only the basal 1 or 2 feet of the trunk. This behavior assures the MPB population will remain at a low level until the stand matures and beetles infest larger trees having thick phloem that will support high survival rates necessary for an outbreak.

METHODS

Several hundred stands of lodgepole were measured in the western United States. These were limited to the lower elevational levels where stands would be climatically susceptible to MPB infestation, thus making methods more directly comparable, since some have a climatic variable (Amman and others 1977; Safranyik and others 1974), where others do not. Outbreaks are not as likely to occur in the moderate to low areas of climatic suitability, and much of the loss occurring in these hazard zones is the result of beetles emigrating from high-hazard stands at lower elevations.

Stands were selected at random from suitable candidate stands within the zone of climatic suitability for MPB, using a table of random numbers. Stands ranged in infestation history from no recent infestation to those that had just completed an outbreak. Stands that had recently (within the past 10 years) been disturbed by human activity or wind were avoided. Stands that had other species present were sampled, as long as they had 75 percent or more lodgepole pine.

Each stand was sampled, using a 10-BAF variable plot cruising method. Ten plots located 5 chains apart on two lines located 5 chains apart (five plots per line) were used in each stand. However, in the case of odd-shaped stands, plots were located in any pattern that maintained spacing. The following data were recorded for each plot: (1) elevation; (2) habitat type; (3) slope; (4) aspect; (5) diameter at breast height (5 inches and larger) and species of tree; (6) alive or dead; (7) year tree killed (current year: tree green, fresh beetle attacks; 1 year old: most foliage retained and bright orange; 2 years old: one half or more foliage retained and dark brownish orange; older than 2 years); (8) pitch-outs and strip attacks; (9) other insect, disease, or mechanical injury; (10) two increment cores 180 degrees apart; (11) from each bored tree: height, crown length, crown class, sapwood depth, phloem thickness (green trees only); and (12) stand stocking.

Multiple regression analysis was used to determine which variable or set of stand variables best predicted lodgepole pine losses to MPB by broad geographic area. Only variables with F probability of 0.15 or less were considered. Variables included in the regression were: (1) basal area, (2) trees per acre, (3) quadratic mean diameter, (4) stand density index, (5) phloem thickness, (6) basal area of trees having phloem $\geq$ 0.10 inch, (7) age, (8) radial growth during last 5 years, (9) radial growth during previous 5 years, (10) sapwood thickness, (11) number of growth rings in last centimeter, (12) grams of wood per square meter of foliage in killed

trees, (13) grams of wood per square meter of foliage in uninfested trees, (14) elevation, and (15) latitude. Stands that had no mortality attributable to MPB were excluded from the analyses. Additionally, seven stands were selected for multiple regression (maximum R^2 procedure) of within-stand factors. However, because of the small sample of increment cores per plot, reliable estimates for variables related to tree growth could not be calculated for individual plots. The dependent variable used was percent of trees killed by MPB. Independent variables were: (1) measures of density, consisting of trees per acre (TPA), basal area (BA), and stand density index (SDI); and (2) measures of tree size, consisting of average diameter for trees $\geq$ 5 inches d.b.h. (AVGD), quadratic mean diameter for trees $\geq$ 5 inches d.b.h. (QMD), and percent of lodgepole 5 to 6.9 inches d.b.h. (%5-6.9). The seven stands were selected on the basis that (1) the current MPB infestation was almost completed, as indicated by current MPB activity, and (2) each stand was in a different National Forest.

GEOGRAPHICAL DIFFERENCES

One of the main objectives of a test of hazard rating methods was to determine if there were strong geographical influences. Stepwise multiple regression was used to determine which variables were most clearly associated with percent cumulative tree mortality by area--Central Rockies, Northern Rockies, and Pacific Northwest. The Central Rockies included the Gallatin National Forest and all National Forests south to Colorado. The Northern Rockies included all remaining National Forests in Montana, northern Idaho, and eastern Washington. The Pacific Northwest includ-ed the remaining National Forests in Washington and all National Forests in Oregon. In the stepwise procedure, variables that were not significant at the 0.15 level were excluded.

In the Central Rockies, the stepwise procedure showed cumulative lodgepole pine mortality was significantly related to two variables, latitude (F probability 0.016) and trees per acre (F probability 0.069). Cumulative mortality was negatively related to both of these factors. The negative relationship to latitude suggests decreased mortality occurs going north from Colorado to southern Montana. The decrease in mortality as latitude increases is probably an artifact related to when beetle infestations occurred. More recent MPB outbreaks have occurred in parts of Colorado and in northeastern Utah, whereas MPB populations farther to the north in the Central Rockies have been low for many years, following earlier outbreaks in the 1960's and 1970's. Past observations show tree mortality was high in the Bridger-Teton, Targhee, and Gallatin National Forests (Amman and Baker 1972; McGregor 1978). Most of these dead trees have been harvested or have fallen down. Therefore, we consider the relationship of less mortality with increased latitude within the Central Rockies to be false. The inverse relationship of mortality with trees per acre is consistent with past observations (Amman 1978), where heaviest tree losses occurred in less dense stands that contained a high percentage of large-diameter trees.

The stepwise procedure for data from the Northern Rockies also showed two variables having F probabilities less than 0.15--phloem thickness (F = 0.077) and stand density index (F = 0.097). Both were inversely related to cumulative tree mortality. Phloem thickness has in the past been related positively with MPB brood production (Amman 1972). However, once the MPB in the Northern Rockies build up to large numbers, they appear to overwhelm most trees. In many stands, the few remaining live trees on which to measure phloem are usually small-diameter trees that have thin phloem. The inverse relationship of cumulative mortality to SDI is consistent with the findings of Anhold and Jenkins (1987) and with increased mortality as trees per acre decline, as noted for the Central Rockies. Anhold and Jenkins (1987) found generally that mortality was greatest at SDI values between 125 and 250, having losses up to 90 percent at SDI 150. Tree losses in stands having SDI values of 90 to 125 were up to 20 percent. An SDI of 125 corresponds to crown closure, and an SDI of 250 corresponds to the beginning of full site occupancy (McCarter and Long 1986). Anhold and Jenkins (1987) suggested that trees in stands with an SDI above 250, even though of large diameter, would have thinner phloem and thus have less potential for producing beetles. Stands having SDI values below 125 could produce more resin to repel beetle attacks. Recent observations of tree vigor and microclimate in thinned and unthinned lodgepole stands suggest that microclimate plays an important role in reduced infestation of lightly stocked stands (Amman and others 1988; Bartos and Amman 1989).

In the Pacific Northwest, as in the other geographic areas, only two variables had F probabilities less than 0.15--grams of wood per square meter of foliage in killed trees ($P < 0.112$) and elevation ($P < 0.038$). Cumulative tree mortality was positively related to grams of wood. Increased tree mortality, with an increase in grams of stem wood produced per square meter of foliage, is opposite of observations by Waring and Pitman (1980) in Oregon. Therefore, additional work, particularly within stands, needs to be done to verify the relationship of grams of stem wood to tree mortality. Trees producing high wood-to-foliage ratios were just as likely to be infested as those producing lower wood-to-foliage ratios in the Central (Amman 1985) and Northern Rockies (Amman and others 1988). The inverse relationship of tree mortality to elevation is consistent with observations in southeastern Idaho and northwestern Wyoming (Amman and Baker 1972), and in northern Utah (Amman and others 1973). As elevation increases, weather is generally cooler and the MPB life cycle becomes delayed and out of synchrony with weather conditions for best brood survival (Amman 1973; Reid 1962).

WITHIN-STAND DIFFERENCES

When analyzing data obtained over a large geographic area, unexplained variance tends to be large. Therefore, the seven selected stands were analyzed to determine which of six variables explained the largest amount of variance in cumulative tree mortality within each stand.

The variable accounting for the greatest amount of variance in the percent of lodgepole pine mortality differed by stand. Measures of density were strongest in three of the stands--TPA in one, BA in one, and SDI in one. Measures of tree diameter were strongest in four stands--percent of trees 5 to 6.9 inches d.b.h. in one, QMD in two, and AVGD in one. The largest amount of variance explained by the regressions of individual factors within individual stands ranged between 9.4 and 68.6 percent (table 1). In multivariable models, variance explained in two variable models ranged between 34.5 and 79.9 percent; three-variable models ranged between 44.8 and 84.3 percent; four variable models ranged between 45.3 and 86.7 percent; five-variable models ranged between 60.5 and 95.4 percent, and six-variable models between 59.3 and 96.8 percent (table 2).

Going from the broad areas (Pacific Northwest, Northern Rockies, and Central Rockies) to the individual stand, much of the variance associated with the broad areas is eliminated and a much better prediction of mortality can be obtained. Tree size (QMD and AVGD) was positively correlated with tree mortality in five of the seven stands. This is consistent with observations that MPB show preference for lodgepole of large diameter (Cole and Amman 1969; Hopping and Beall 1948). These are the trees in which reproductive success is best (Amman 1969; Cole and others 1976; Reid 1963), probably because of generally thicker phloem, the food of developing larvae (Amman 1972), and greater moisture retention during beetle development (Cole and others 1976). Stand density (BA, TPA, SDI) was negatively correlated to tree mortality in five of the seven stands and always opposed (negative or positive) correlations with tree size. As basal area and SDI increase, tree competition increases and phloem thickness declines, thus beetle production declines. This is consistent with Anhold and Jenkins (1987), except at SDI values below 100, where high mortality occurred in our observations. Although SDI is made up of tree size and stand density, it often appears as a significant variable with BA and QMD. The percent of trees 5 to 6.9 inches d.b.h. is that portion of the stand that is not very susceptible to beetle infestation. Tree mortality was negatively correlated with trees 5 to 6.9 inches d.b.h. in five of the seven stands. Of the two positive correlations, one occurred when mortality was negatively correlated with stand density but positively correlated with tree size, and the second occurred under opposite conditions. When trees are infested in these diameters, few beetles are produced, on the average, resulting in a population deficit.

Although there are additional factors that will be explored for use in predicting lodgepole pine mortality when stands have been revisited and radial growth measures completed, these analyses suggest that a good combination may consist of a measure of (1) tree size (QMD), (2) stand density (BA), (3) percent of trees 5 to 6.9 inches d.b.h., and (4) an SDI that integrates tree size and stand density.

Terry Shore (these proceedings) has already progressed into assessing the performance of individual hazard rating methods in British Columbia. The next step in hazard rating analyses in western United States is to revisit plots to record any additional mortality and then test all existing methods and any new combinations, such as those in this paper. Until these tests are completed, managers should feel safe in using lodgepole pine diameter and a measure of climatic suitability to assess stand susceptibility to MPB (Amman and others 1977; Cole and McGregor 1983; Safranyik and others 1974).

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Table 1--Proportion of variance in percent tree mortality caused by mountain pine beetle (dependent variable) explained by different combinations of tree and stand factors

	National Forest							
Independent variable	Flathead	Lolo	Colville	Kootenai	Deschutes	Freemont	Winema	Forests combined
One-variable model:								
Trees per acre	0.438	0.266	0.018	0.183	0.071	0.023	0.369	0.0064
Basal area	0.061	0.223	0.094	0.066	0.008	0.001	0.454	0.00001
Stand density index	0.171	0.237	0.070	0.100	0.021	0.002	0.501	0.0003
Percent trees 5-6.9 inches DBH	0.534	0.061	0.054	0.299	0.111	0.289	0.001	0.058
Quadratic mean DBH	0.223	0.011	0.006	0.331	0.686	0.005	0.245	0.077
Average DBH	0.243	0.004	0.016	0.330	0.674	0.012	0.170	0.082

Table 2--The best one- to six-variable models based on maximum R^2 procedures

Number of variables	National Forest															
	Flathead		Lolo		Colville		Kootenai		Deschutes		Freemont		Winema		Forests combined	
	Model	R^2	Model	R^2	Model	R^2	Model	R^2	Model	R^2	Model	R^2	Model	R^2	Model	R^2
1	[1]%5-6	0.534	TPA	0.266	BA	0.094	QMD	0.331	QMD	0.686	%5-6	0.289	SDI	0.501	AVGD	0.082
2	[2]%5-6 BA	0.652	TPA %5-6	0.365	BA SDI	0.345	QMD %5-6	0.423	QMD TPA	0.799	%5-6 AVGD	0.540	BA AVGD	0.534	AVGD TPA	0.098
3	%5-6 SDI TPA	0.722	%5-6 TPA QMD	0.518	BA SDI %5-6	0.672	%5-6 QMD AVGD	0.448	AVGD %5-6 SDI	0.843	%5-6 AVGD QMD	0.626	QMD BA SDI	0.555	AVGD SDI BA	0.126
4	%5-6 TPA SDI BA	0.749	BA %5-6 QMD AVGD	0.529	AVGD QMD BA SDI	0.829	%5-6 QMD AVGD TPA	0.453	%5-6 BA AVGD QMD	0.867	%5-6 AVGD QMD TPA	0.647	QMD BA SDI TPA	0.582	AVGD BA SDI TPA	0.152
5	SDI BA QMD AVGD TPA	0.871	TPA SDI BA AVGD %5-6	0.954	AVGD QMD BA SDI TPA	0.908	%5-6 BA SDI TPA AVGD	0.566	TPA SDI BA AVGD QMD	0.886	%5-6 AVGD QMD SDI BA	0.651	AVGD BA SDI TPA %5-6	0.605	BA SDI TPA AVGD QMD	0.152
6	QMD AVGD BA SDI TPA %5-6	0.871	BA SDI TPA AVGD %5-6 QMD	0.968	AVGD QMD BA SDI TPA %5-6	0.924	%5-6 TPA SDI BA AVGD QMD	0.593	AVGD BA QMD TPA SDI %5-6	0.910	%5-6 AVGD QMD BA SDI TPA	0.655	BA SDI TPA AVGD %5-6 QMD	0.613	BA SDI TPA AVGD QMD %5-6	0.152

[1]Abbreviations stand for the following: %5-6 = percent of lodgepole in the 5 to 6.9-inch d.b.h. class; TPA = number of trees per acre; BA = square feet of basal area, all tree species; SDI = stand density index; QMD = quadratic mean d.b.h. of all lodgepole; AVGD = average d.b.h. of all lodgepole 5 inches and larger d.b.h.

[2]Variables in multivariable models are listed from most to least significant.

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A PRELIMINARY EVALUATION OF HAZARD RATING SYSTEMS FOR THE MOUNTAIN PINE BEETLE IN LODGEPOLE PINE STANDS IN BRITISH COLUMBIA

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ABSTRACT: Five hazard rating systems were evaluated for 59 lodgepole pine stands that had experienced mountain pine beetle epidemics. None of the methods was found to satisfactorily predict the amount of mortality which would occur as a result of the beetle. We feel the primary source of variation inhibiting proper analysis of these methods is a measure of beetle population pressure, and that a risk model which incorporates both stand hazard and beetle population pressure, such as proposed by Paine and others (1984), would better describe stand risk to the mountain pine beetle.

INTRODUCTION

A number of systems have been proposed for rating the hazard of lodgepole pine stands to mountain pine beetle (MPB) damage. A reliable hazard rating system would allow forest managers to prioritize stands for harvesting or treatment. The performance of some of these hazard rating systems in various forest types has been discussed previously in a number of papers (Mahoney 1978; McGregor and others 1981, 1986; Amman 1985; Shrimpton and Thomson 1983, 1985; Stuart 1984; Katovich and Lavigne 1985). In 1982, as part of the Canada-United States Mountain Pine Beetle / Lodgepole Pine Agreement it was decided to evaluate six hazard rating systems (Safranyik and others 1974,1975; Amman and others 1977; Mahoney 1978; Berryman 1978; Schenk and others 1980; Waring and Pitman 1980) over a large number of lodgepole pine stands throughout the range of the beetle in order to identify the best possible system for a given region or forest type. This paper reports our early findings on five of the systems for stands in the Cariboo Region of British Columbia.

The terms hazard and risk are often used interchangeably or interpreted differently. We define risk as the probability of an infestation starting in a given stand. Hazard is a measure of the characteristics of a stand that affect its susceptibility to the MPB once it is under attack.

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In British Columbia, forest land covers approximately 116 million acres (47 million ha). Almost 25% of the volume harvested currently is in lodgepole pine. In the Cariboo Forest Region approximately half the volume harvested is lodgepole pine (Anon. 1986). Since 1972 when the MPB infestation began in the western part of the region, millions of trees have been killed over hundreds of thousands of acres resulting in serious disruption of the timber supply.

METHODS

Fifty-nine stands were sampled in the Cariboo Forest Region based on 10 prism plots (BAF 10-english units) spaced at 328 foot (100 m) intervals. Species and diameter at breast height (DBH) were recorded for all sample trees and two increment cores taken at 180° from each of three sample trees in each plot. Phloem thickness was measured in the field while sapwood width, age and yearly increments were measured in the laboratory with a Measuchron tree ring measuring device linked to a VAX computer. Following the collapse of the MPB infestation in the Cariboo, these stands were revisited and plot trees killed by the MPB were recorded.

RESULTS

In the sample stands the species mix ranged from 60-100% lodgepole pine with Douglas-fir, white spruce and trembling aspen being the most commonly associated species. Stand age was primarily mature and overmature, stand density ranged from 137 to 595 trees per acre (338 to 1,470 per ha) and average stand diameter ranged between 5.5 and 12.5 inches (14 and 32 cm).

Analysis of Hazard Rating Methods

Amman and others 1977--This method involves rating elevation-latitude, mean stand DBH of lodgepole pine and mean stand age each on a scale of 1-3 according to established thresholds. The product of these three ratings gives the stand hazard, which is interpreted in terms of the percentage mortality to lodgepole pine trees greater than 8.5 inches DBH as follows: 1-9 low hazard (< 25% of trees), 10-18 moderate hazard (25-50% of trees), and 27 high hazard (> 50% of trees). There is one exception; if all three values are moderate (i.e. 2 x 2 x 2) the value 8 is considered to represent moderate hazard. This means there are 19 ways to get a low hazard, seven ways to get a moderate hazard and only one way to get a high hazard.

Of the 59 stands, mortality was estimated correctly in 14 stands (24%)(Table 1). Most of the error involved rating stands as moderate when low mortality occurred. Of 32 stands rated moderate only three were correctly identified. When the stands with no mortality were removed from the analysis only 8% of the low mortality plots were predicted correctly (Table 1).

Table 1—Observed and predicted tree mortality based on the system of Amman and others (1977)(see text for definitions)

	Low	Moderate	Severe	Total
Observed	41 (25)	4	14	59 (43)
Predicted	13	32	14	59
Correct	8 (2)	3	3	14 (8)
% Correct	20 (8)	75	21	24 (19)

Numbers in parentheses refer to stands experiencing some tree mortality by MPB.

Mahoney 1978—This method is based on the Periodic Growth Ratio (PGR) which is calculated as the current 5 year radial increment divided by the previous 5 year radial increment of dominant and co-dominant lodgepole pine trees. A PGR of less than 0.9 would indicate declining vigor and increased susceptibility to MPB resulting in greater than 10% tree mortality for trees greater than 5 inches (12.5 cm) DBH, whereas PGR greater than 0.9 would indicate a vigorous stand that is resistant to MPB. In this case expected mortality would be less than 10% of trees 5 inches DBH. Mahoney limited the application of his method to stands with favourable climate, average tree age greater than 60 years and average diameter greater than 7 inches (17.5 cm).

Of the 46 eligible stands, 23 (50%) were predicted correctly, which in a two class system is what would be expected by chance. The method was more successful at predicting low mortality than high mortality (Table 2). When stands with no mortality were removed from analysis 72% of the low mortality stands were predicted correctly.

Table 2—Observed and predicted tree mortality based on the system of Mahoney (1978)

	Low(‹10%)	High(›10%)	Total
Observed	33 (18)	13	46 (31)
Predicted	30	16	46
Correct	20 (13)	3	23 (16)
% Correct	61 (72)	23	50 (50)

Numbers in parentheses refer to stands experiencing some tree mortality by MPB.

Schenk and others 1980—This method uses crown competition factor (CCF), a measure of stand density (Krajicek and others 1961), and the proportion of the stand basal area represented by lodgepole pine (PLPBA) to calculate a stand hazard rating (SHR) as:

$$SHR = CCF\ (PLPBA/100)$$

The SHR is then related to mortality, in terms of the percentage of lodgepole pine basal area killed (%BAK) by the beetle.

We found that %BAK was inversely related to CCF (Fig.1). A similar finding was reported by McGregor (and others 1981;1986). Figure 2 shows the relationship between %BAK and SHR and the fit of one possible model to this relationship. Although there are no data at SHR less than 0.45 it is reasonable to assume that %BAK drops to zero at very low stand densities or percentage pine component (Fig. 2). This model suggests that MPB-caused mortality decreases with increased stand density through most stands rather than increases as hypothesized by Schenk and others (1980).

Berryman 1978—This method uses the ratio of PGR/SHR as a measure of Stand Resistance, and the percentage of the lodgepole pine basal area having phloem thicker than 0.1 inch (2.5 mm) as a measure of a stand's ability to support a beetle population.

The percentage of stand basal area with phloem greater than 0.1 inch did not appear to be a relevant factor in the model (Fig. 3). There was some separation between severely damaged stands (greater than 40% tree mortality) and the low and moderate mortality classes, but very little separation between the latter two. However, the greatest mortality occurred at the highest level of resistance (Fig. 3). This reversal is probably due to the inverse relationship found between mortality and SHR, on which Berryman's method is partially based.

Waring and Pitman 1980—This method involves calculating Growth Efficiency as the ratio of current growth (grams of stemwood produced) to crown leaf surface. These values are obtained through relationships to basal area increment and sapwood basal area (Mitchell and others 1983). Trees producing less than 50 g of wood per m^2 foliage are highly susceptible, trees producing 51 to 100 g are moderately susceptible, and trees producing more than 100 g are highly resistant to MPB attack (Amman 1983). The highest Growth Efficiency found in our study was around 60 which would indicate that the majority of stands were highly susceptible (Fig. 4). There appeared to be no direct relationship between the amount of mortality and Growth Efficiency within the range of values found in this study (Fig. 4).

DISCUSSION

None of the five methods examined provided a useable system for hazard rating stands. The PGR system (Mahoney 1978) may be theoretically unsound because PGR should tend to decline at a tree age of about 30 years (Shrimpton and Thomson 1981), and because it does not differentiate between fast and slow growing trees (McGregor and others 1981; Katovich and Lavigne 1986). The underlying hypothesis in the SHR method (Schenk and others 1980) appears to be the reverse of what is found in the field. However, it should be noted that CCF and SHR are significantly related to tree mortality and therefore should be integral components of a hazard rating system. Berryman's method (Berryman 1978), being based on

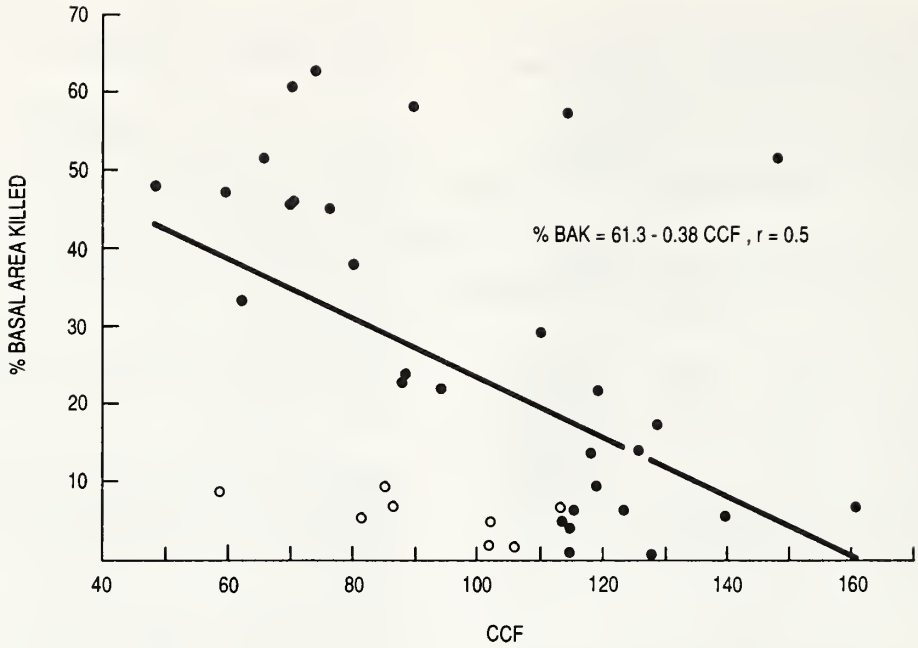

Figure 1—The inverse relationship between percentage of lodgepole pine basal area killed by mountain pine beetle and crown competition factor (CCF) (Krajicek and others 1961).

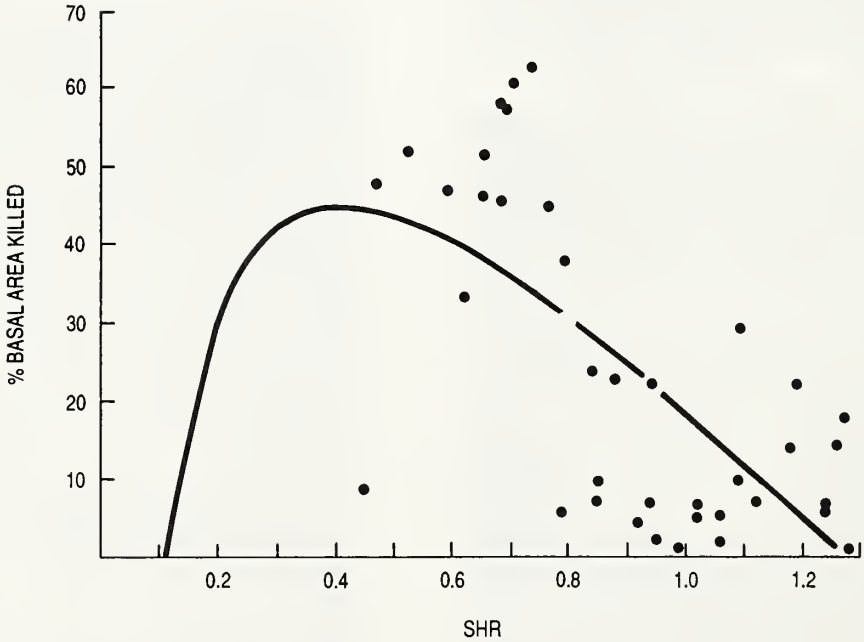

Figure 2—A fit of the model Y=a+b/X+cX to the relationship between percentage lodgepole pine basal area killed and Stand Hazard Rating (SHR) as defined by Schenk and others (1980); a=106.5, b=-12.27, c=-75.73, r=0.67.

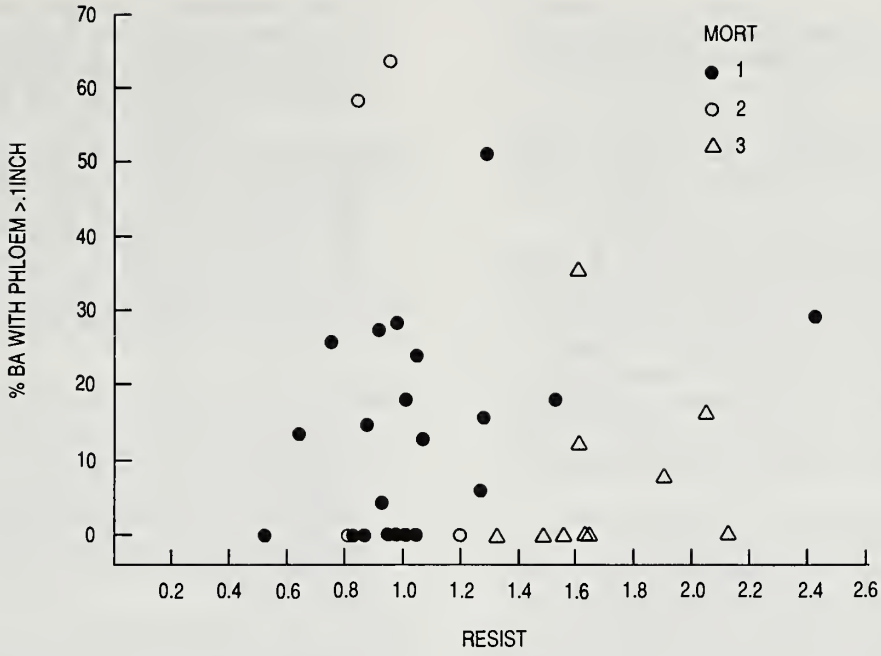

Figure 3—Mortality classes as a function of the percentage of basal area having phloem greater than 0.1 inch (2.5 mm) and resistance (Berryman 1978); 1 = ‹ 11%, 2 = 11 - 40 %, 3 = › 40 % of lodgepole pine basal area killed.

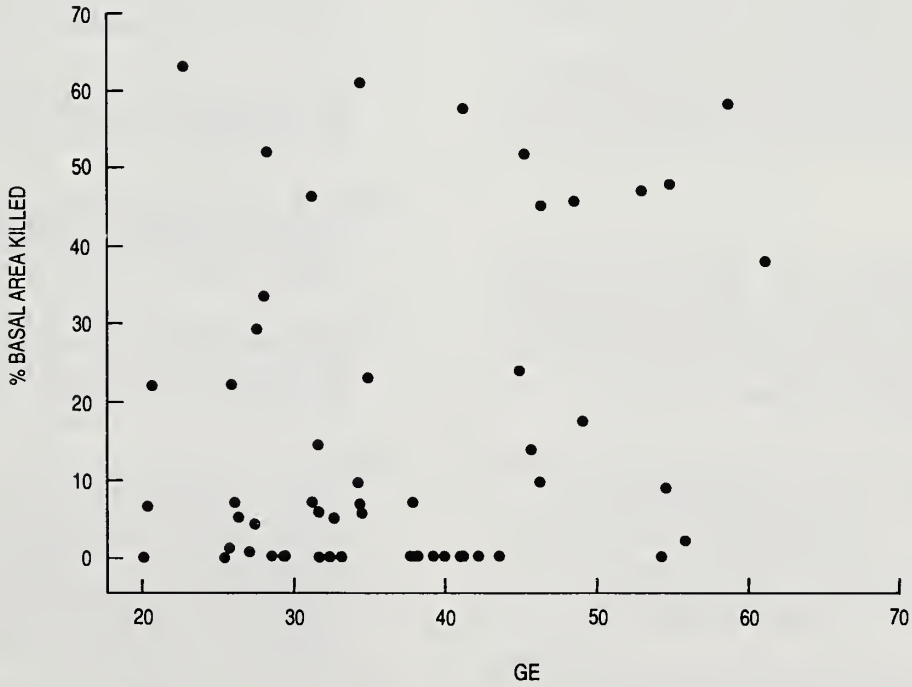

Figure 4—The relationship between percentage basal area killed and growth efficiency (GE) (Waring and Pitman 1980).

PGR and SHR suffers from the problems inherent in those methods as well as from an apparently insignificant relationship between percentage of basal area having phloem greater than 0.1 inch and mortality. While we know that MPB shows a preference for larger diameter trees, and produces more and larger brood in thicker phloem, phloem thickness is poorly related to DBH (Shrimpton and Thomson 1985). The Growth Efficiency method (Waring and Pitman 1980) successfully predicted that the majority of stands were highly susceptible. However, the system does not provide a measure of expected mortality which limits its usefulness. The poor results obtained with the system of Amman and others (1977) may be due to differences in the threshold values of the component variables in the British Columbia forests. A problem with most of the systems is that they do not account for variability due to MPB population pressure.

To evaluate the probability of a given stand being attacked and sustaining damage it is necessary to know both the susceptibility of the stand to MPB damage and the probability of a MPB population entering the stand. The conceptual model proposed by Paine and others (1984) states that risk is a function of hazard and population pressure. We agree with this concept. The hazard rating methods so far have concentrated on determining stand susceptibility. However, if variability due to population pressure is not accounted for there will always be a poor relationship between stand hazard and damage. A stand can be highly susceptible to MPB but if there is no population in the area it is at low risk. Conversely, a stand of relatively low susceptibility can receive more than its expected level of damage if it is in the path of a raging epidemic. By including both indicators of beetle population pressure and stand hazard, a dynamic estimator of stand risk can be calculated on an annual or periodic basis. To develop the best hazard rating method, the most promising indicator variables should be compared for stands experiencing similar MPB population pressure.

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CASE HISTORY: APPLICATION OF RISK ASSESSMENT--FLATHEAD NATIONAL FOREST

Paul R. Beckley

ABSTRACT: In 1978, personnel of the Tally Lake Ranger District, Flathead National Forest, MT, initiated a risk assessment process and revised lodgepole pine harvest program to combat a potential mountain pine beetle epidemic. The epidemic was extensive by 1985. The INDIDS mortality model became available and was run for every stand. To consolidate information, a data base called X-BEETLE was developed. Assumptions were largely correct and risks taken paid dividends. Success in managing a large epidemic depends on sound information and ability to analyze it properly.

INTRODUCTION

Mountain pine beetle populations have existed in an endemic condition for many decades in the Flathead National Forest. It was only a matter of time until extensive lodgepole pine stands originated by fire acquired the characteristics necessary to generate a mountain pine beetle epidemic. The following is a summary of how one ranger district in the Flathead National Forest anticipated, prepared, and successfully dealt with a major epidemic of mountain pine beetle.

EPIDEMIC SITUATION

Around 1978 it became evident that the vast mature lodgepole pine stands in the Tally Lake District of the Flathead National Forest had reached conditions conducive to a major mountain pine beetle epidemic. The district was obviously sitting on a volatile situation that needed immediate attention. Mountain pine beetle populations had already increased to epidemic levels in the Gallatin National Forest and new epidemics were developing in parts of the Beaverhead, Kootenai, and Lolo National Forests. The situation close to home was just as bad if not worse. Epidemic levels were reached in the Glacier View Ranger District of the Flathead National Forest in 1975 with about 80 acres infested. By 1978 this had increased to 80,000 acres. An infestation in Glacier National Park increased from 1,180 acres in 1972 to 165,000 acres in 1978. This combined to almost 225,000 acres, which presented a formidable threat to the Tally Lake District. At the same time the Tally Lake District continued to show surprising resistance to attack with only scattered small activity centers throughout the district.

ORIGINAL PLANNING EFFORTS--PHASE I

Considering the large potential for resource losses in the Tally Lake Ranger District as well as other nearby districts, it was decided that an accelerated harvest program concentrating on high-risk lodgepole pine should be attempted. In July 1978 the Tally Lake District decided to inventory and evaluate all lodgepole pine stands for their susceptibility to mountain pine beetle. The system used to determine risk was based on that developed by Amman and others in 1977. The rating was based on average tree diameter, age, and elevation. From this survey it was estimated that approximately 38,000 acres and 320 million board feet of high-risk lodgepole existed in the Tally Lake District.

In October 1978 the Flathead National Forest held an interagency and industry meeting to establish the Northwest Montana Mountain Pine Beetle Task Force. It was the function of this group to develop alternative strategies for coordinated management of the mountain pine beetle hazard. The resulting direction was finalized in early 1979 and was documented in an environmental assessment report.

One of the major purposes of the mountain pine beetle harvest program was to capitalize on the economic differential between green and dead lodgepole pine. This differential was substantial at that time. The basic structure of the harvest program was to:

- Substitute lodgepole pine harvest for other species.
- Harvest one half of high-risk lodgepole over a 3-year period (160 MMBF).
- Shift the majority of the forest harvest to the Tally Lake Ranger District and not change the forest total.
- Emphasize preroading of high-risk lodgepole pine stands with the use of capital investment funds.

Paper presented at the Symposium on the Management of Lodgepole Pine to Minimize Losses to the Mountain Pine Beetle, Kalispell, MT, July 12-14, 1988.

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-Reevaluate epidemic status and management direction in 1982 (Phase II). The assumption was that the epidemic would be well under way by 1982 and the program would evolve to one of sanitation-salvage harvesting rather than regeneration harvesting of green stands.
-The resulting 1980-1982 timber sell and harvest levels can be seen in table 1. This includes all species including lodgepole pine for a total sell program of 230.9 MMBF over a period of 3 years.

Table 1--Timber volume sold and harvested--Tally Lake District, Flathead National Forest

Fiscal Year	Timber Sold(MBF)	Timber Harvested (MBF)
1975	37.6	25.6
1976	24.8	31.5
1977	44.3	54.2
1978	11.1	22.5
1979	10.7	18.9
1980	136.2	27.4
1981	32.4	38.2
1982	62.3	16.2
1983	27.2	29.7
1984	20.7	57.5

REPLANNING--PHASE II

As previously mentioned, a reevaluation was planned in 1982 to determine if any planning revisions would be necessary. Several situations that were originally assumed in Phase I did not materialize. The first and most important assumption was that the epidemic had not developed as expected. The mountain pine beetle status in the Tally Lake District was still of endemic proportions. Another unexpected event was that the timber sales that were being sold were not being harvested because of a poor lumber market. Because of these unexpected events, it was decided that any replanning would be postponed. However, in 1983 significant mortality in lodgepole pine began to occur. An even more spectacular buildup occurred in 1984 and by 1985 the entire south end of the Tally Lake District was in an epidemic situation. With this new development, Phase II planning began.

In this same general time period several other things were developing that would be of great assistance in future planning. These were:
-Silvicultural examinations had been completed for the entire Tally Lake District.
-Several silvicultural and chemical techniques were being developed to decrease the impact of mountain pine beetle.
-The Data General computer system along with a powerful data base and report writing software was being installed throughout the Forest Service.
-The INDIDS mountain pine beetle mortality model was being developed.

We also recognized by this time that it would be extremely helpful to have a data base system that could isolate lodgepole pine from other species. The existing timber stand management record system did not separate lodgepole from other species.

Another important point to recognize was that the probability of an epidemic in any particular stand was no longer a variable. It was safe to assume that there was 100 percent probability that all stands would eventually be affected. The only question was how much could we expect to lose from each stand and how we should use this information as the primary criterion for prioritizing stands for harvest.

It was felt that the INDIDS mountain pine beetle mortality model could provide us with the necessary information to make management decisions. The model basically:
-Predicts the lodgepole pine mortality for each year of an epidemic from beginning to end and gives total predicted volume losses for each individual stand.
-It is designed to run directly from stand examination data files (R-1 Edit).

The INDIDS model was run for every stand in the Tally Lake District that contained lodgepole pine. To bring all this new information together it was obvious that it would be useful to develop a data base to hold the applicable information and present it in a format that made it analyzable. With this in mind we designed a data base called X-BEETLE. It is a Data General data base interfaced with a Data General report writer program called PRESENT. By entering key mortality items from the INDIDS output along with a few stand exam data items the following report information could be generated:
-Stand identification
-Stand acres
-Preepidemic stand characteristics
-Postepidemic characteristics
-Equivalent clearcut acres

The stand characteristics are described in terms of MBF/acre, cubic ft/acre, basal area/acre, and total stand MBF.

The standard programs for X-BEETLE have been designed to produce the following reports:
-Stands may be listed in order of stand identification number. The report may include all stands in a ranger district, all stands in a particular compartment, and combinations of compartments or subcompartments. It may also list any combination of individual stands. This has proven to be extremely useful in designing alternatives for analysis.
-Stands may be listed in order of predicted losses in terms of

MBF/acre. They may also be limited to those areas discussed above.
- The report may also be designed to list only stands with predicted losses greater than 10 MBF/acre, 5 to 10 MBF/acre, and less than 5 MBF/acre.
- A report can be generated to produce only totals for specified areas.

The generation of equivalent clearcut acre (ECA) information has proven extremely useful for those areas where increased water yield may be a limiting factor for planned activities. This information predicts the estimated impact of a mountain pine beetle epidemic on increased water yield. It is especially helpful in determining the hydrologic impact of no action or deferred action alternatives. The data are generated by a linear equation based on a reduction in basal area once a certain threshold has been exceeded.

To visually perceive the spatial pattern of predicted mortality, it was decided that mapping should be done. Stands were divided into three categories based on predicted mortality. This was done on TSMRS compartment maps for the entire district. This function can now be done automatically with the multilevel resource information system (MURIS).

With this new information it was decided that the future strategy on the Flathead National Forest would be based on the following assumptions:
- Revert back to the preepidemic sale level of 30 MMBF/year.
- Epidemic will have run its course in the next 5 years or at least 85 percent of the predicted mortality will have occurred.
- Basic district management philosophy will not change.

Based on these assumptions the district strategy will be:
- Two thirds of the annual sale program will be concentrated in stands where predicted lodgepole pine mortality exceeds 10 MBF/acre.
- An effort will still be made to maximize the green vs. dead value differential by harvesting ahead of mortality.
- One third of the program will harvest mortality and consist of other miscellaneous sales.
- After 4 years there will be a shift away from lodgepole pine and back to mixed species. However, an effort will be made to continue to harvest dead lodgepole with the small sales program.

CONCLUSIONS

The success in managing a large mountain pine beetle epidemic depends heavily on not only the information available but on one's ability to manage or analyze the information. Overall objectives should be fairly clear before data are gathered and analyzed. A manager should also feel comfortable in making important decisions based on probabilities. In the case of the Tally Lake District it was highly probable that a significant amount of lodgepole pine would be lost to mountain pine beetle and harvesting was based on this assumption. The assumptions turned out to be largely correct and the risks that were taken paid off significantly. However, much of the success has to be attributed to the ability of the district to realize the importance of the collection and management of appropriate information. This could not have been done nearly as efficiently as it was without the availability of the INDIDS mortality model or the X-BEETLE data base.

The INDIDS model proved to be slightly conservative in its mortality predictions for the Tally Lake District. However, it can be calibrated if desired to reflect local conditions.

As previously mentioned the primary purpose of preepidemic harvesting was to capitalize on the economic differential between green and dead timber. Another benefit that was assumed is that the epidemic effects may be reduced by removing stands of large-diameter lodgepole pine, thus reducing insect population growth. However, this did not occur because of: (1) the significantly delayed harvest of lodgepole pine because of poor market conditons and (2) the enormous beetle population.

In summary, it is obvious that all the anticipated losses of lodgepole pine cannot be harvested. For this reason prioritization is extremely important to maximize objectives. Therefore, it is important to determine what objectives actually are from the very beginning of the program and to design it to meet these objectives.

A TOOL FOR ASSESSING THE IMPACTS OF MOUNTAIN PINE BEETLE AND RELATED MANAGEMENT STRATEGIES

Merrill S. Davis and William B. White

ABSTRACT: The Forest Pest Management Methods Application Group of the U.S. Forest Service has developed an automated, menu-driven, Decision Support System that operates on Data General minicomputers and utilizes spatial data from a geographic information system, and information from tabular data bases, to run various resource simulation models. Developed to analyze and display the impacts of mountain pine beetle on resource values, this system has the potential for broad application in the analysis of impacts of most management practices on resource values.

INTRODUCTION

Natural Resource Management entails varied and complex problems which the resource manager must solve. Demands on resources come from many sources. These demands often involve an open and direct conflict of values. It is the unique job of the resource manager to evaluate and implement management strategies over time that protect long term resource values, while providing a mix of opportunities to meet resource demands.

Declining budgets and personnel ceilings complicate the job of the resource manager at a time when more informed publics and user groups are raising issues that require detailed analysis and assessment of cummulative effects. As more analysis and study are undertaken, additional constraints surface which require further evaluation and impose new considerations in the formulation of management alternatives.

Just when managers feel they have identified the best management strategy, along comes a destructive agent, such as mountain pine beetle, that affects resource conditions to the extent that management plans must be reevaluated.

Faced with budgetary and time constraints, and required by policy, Congress, and the courts to do a more thorough job of analysis, resource managers must become more efficient and timely in their ability to plan and execute management strategies that are responsive to changing resource conditions and changing public values.

One solution to the resource managers dilemma is better use of analytical capabilities and application of new and emerging technologies. There is a recently developed tool that can enable resource analysis to be completed more timely and efficiently and be displayed in a manner that will greatly aid the decisionmaker in choosing the best management alternative. This tool is a user friendly flexible system framework or shell that links a geographic information system and independent data bases with resource or impact models to estimate the effects of alternative courses of action. This system is known as INFORMS (Integrated Forest Resource Management System).

INFORMS displays the effects of a management activity on a resource value in tabular or graphic form. The structure of INFORMS is modular; this results in flexibility in application because only those models and data which are appropriate for a specific analysis are linked and used. The modular structure also allows model updates or models specific for a certain geographic location to be inserted without major programming changes to the basic INFORMS shell.

BACKGROUND

In 1984, the Nez Perce National Forest entered into a cooperative agreement with the Forest Pest Management Methods Application Group to develop and evaluate an automated decision dupport system to analyze the impacts of mountain pine beetle on resources on the Red River Ranger District. The primary role of the Forest in this project was to describe the current environmental analysis process, identify the resource models commonly used, and provide the spatial and tabular resource data needed for the analysis. Forest Pest Management's primary role was to provide the system design and programming expertise necessary to link the data bases and models together in a single, menu-driven system. In addition to FPM, several other groups cooperated in the development of INFORMS, including the Western Energy Land Use Team of the U.S. Fish

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Paper presented at the Symposium on the Management of Lodgepole Pine to Minimize Losses to the Mountain Pine Beetle, Kalispell, MT, July 12-14, 1988.

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and Wildlife Service, and the University of Arizona. However, FPM has been the primary coordinator throughout the project. The Red River Ranger District is currently in their fifth year of the program and are in the process of writing a user's guide and written evaluation of the system.

In 1987, the Butte Ranger District of the Deerlodge National Forest was given the charter of testing the transferability of the INFORMS Decision Support System. The Butte Ranger District's responsibility is to test the transferability of INFORMS to another geographical location, refine existing resource models to fit their condition, and to test new models as they become available. The Butte District is evaluating the performance of INFORMS by using the system to develop an area analysis on 23,000 acres of National Forest. This analysis will prescribe management practices to be implemented within the analysis area over the next ten years. This analysis unit contains a Congressionally designated recreation area administered by City/County government, a municipal watershed, and a private inholding of 1,100 acres on which 45 families reside. The area is bordered by the interstate highway system and transected by a state highway system. There is an active infestation of mountain pine beetle that has moved into one corner of the analysis unit and is predicted to spread over most of the area. In addition, the analysis unit is in the background viewing area for the City of Butte. When INFORMS was under development on the Red River District of the Nez Perce National Forest, it was known as the Integrated Pest Management Assessment System (IPMAS). However, it became readily apparent that this decision support system had potential far beyond the original charter of assessing the impacts of mountain pine beetle on Forest resource values.

THE TOOL - INFORMS

The Integrated Forest Resource Management System (INFORMS) is a Decision Support System (DSS), aimed at improving the efficiency of resource data and simplifying the use of new technologies in natural resource management. INFORMS combines new and conventional information science technologies into an adaptable computer system environment or shell. Technologies such as advanced computers, spatial analysis functions, data bases (spatial and nonspatial), and simulation models are used.

INFORMS is written in FORTRAN 77 and runs on a Data General MV Series machine. In its present form the software is made up of four major system components (fig. 1). These are: Central Control Module, Model Library, Spatial and Non-spatial Components.

Central Control Module

The Central Control Module (CCM) is the primary component of INFORMS and operates as the logic engine of the system. CCM is the control panel of the user through which all components are linked. User requests are transformed into system commands to define the problem, perform analysis, and present results. The user interface to CCM is menu-driven, providing both text and high resolution graphic capabilities.

Model Library

The Model Library is a collection of programs (models) in files that simulate dynamics of various resources. These include:

PROGNOSIS - A stand growth and yield model that simulates the size and structure of Forest stands over time.

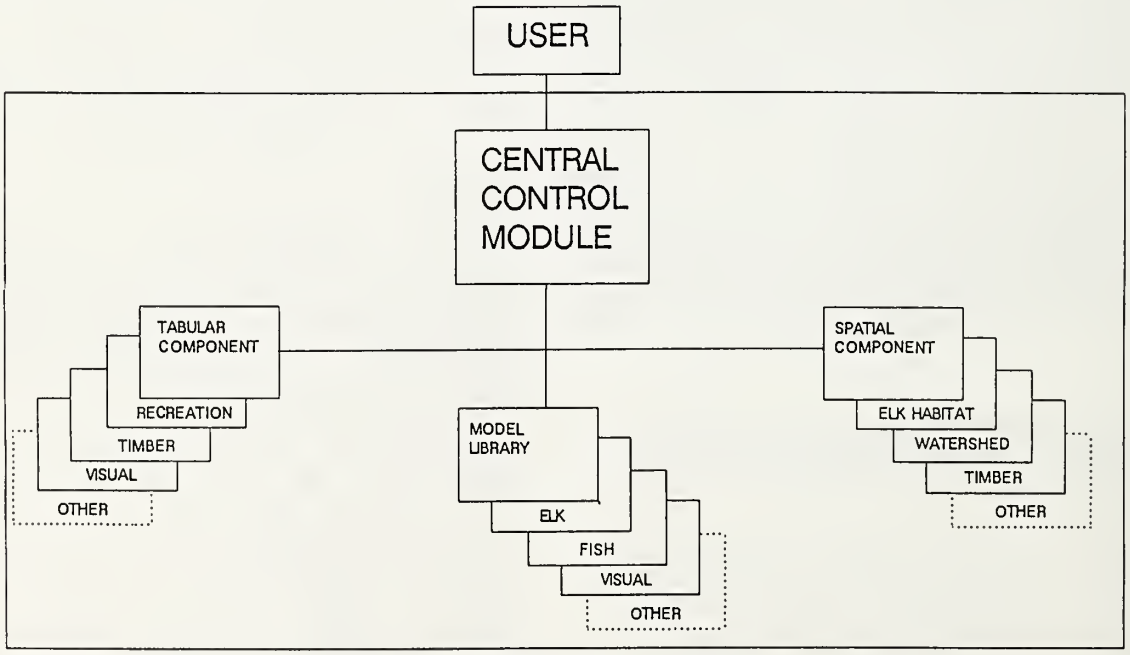

Figure 1.--Informs system diagram showing major components.

NEZSED - A sedimentation model that computes the amount of sediment delivered to critical stream reaches in response to fire occurence, logging, and road building.

FISH - A fisheries model that simulates the response of Brook and Cutthroat Trout to sediment loading in streams.

ELK - An elk dynamics model that identifies the effective security cover based on road use, and attributes of cover.

COVER - A cover model that simulates the growth and structure of wildlife cover over time.

CONTAGION - A dispersion model that projects the rate of spread and extent of mountain pine beetle caused damage.

DLOGPRICE - An econometric model that evaluates the viability of proposed timber sales.

VISUAL - A visual sensitivity model for evaluating aesthetic changes relative to management actions.

WATER YIELD - A water yield model that simulates water run-off in response to road building, logging, and fire occurance.

SBW HAZARD - An insect risk rating model that rates forest stand susceptibility to spruce budworm damage.

Spatial Component

This component contains the spatial functions for manipulating and displaying spatial data. These data are in the form of maps organized into various data themes, such as timber, watersheds, soil types, and roads. The number and type of themes are a function of the problem universal INFORMS is configured to solve. This map information is stored in the polygonal format utilized by the geographic information system - MOSS (Map Overlay and Statistical System). The spatial component also provides a direct link to MOSS so that the user may access the full functions of a general purpose GIS.

Nonspatial Component

Nongeographic data such as timber inventory data and economic data are retrieved from various data bases (local or remote) for input into the various models.

INFORMS resides on the U. S. Forest Service Data General minicomputer on site at the Butte Ranger District, Deerlodge National Forest, Butte, Montana. A high resolution graphics terminal is needed to take advantage of all INFORMS functions. Though not absolutely necessary, all the individual components of INFORMS are on the same computer.

APPLICATION

INFORMS aids the resource manager in the decisionmaking process on the timing, extent, and type of management strategies to be employed to minimize the loss from mortality associated with mountain pine beetle outbreaks.

Predictive Model

INFORMS embodies a predictive model (contagion) that uses stand data to project the rate of spread and the extent of mountain pine beetle damage. Resource managers can use this information to prioritize which analysis units should be analyzed first to prioritize when and where harvest activity should take place.

Scoping

Scoping is the process used to determine the extent of analysis necessary for an informed decision on any proposed activity.

INFORMS aids the scoping process by providing good displays of available resource information; maps of allocation areas, graphs and tabular data on present resource values, and maps and tabular data on predictive models. This professionally displayed information is very useful in informing publics of proposed activities, what resource values are present, and what course of action the mountain pine beetle is expected to take.

Having good information on the resource values within an area to be analyzed and being able to professionally display this information internally, with other agencies, and with interested publics, materially aids in the quality of the scoping process, and reduces the time required to complete this aspect of the process. Many potential or emerging issues can be defused.

Data Collection

Based on the issues and concerns, resource response or impact models are selected for use in the analysis. Model selection determines the amount and kind of data needed to conduct the analysis. Models indicate when data required is not in place and needs to be collected to complete the analysis.

Alternative Development

Alternatives can be developed on the terminal screen over any data theme or combination of data themes that may be useful in developing an alternative.

For example, you may wish to develop an alternative with the following criteria to address an issue or combination of issues: 1) harvest will only take place in Management Area E1, 2) harvest will be restricted to tractor logging, 3) harvest will only take place in stands of high risk lodgepole pine, and 4) areas of critical elk security cover will be avoided by a two sight distance.

To develop this alternative on the terminal with INFORMS to meet the above criteria, we would do the following: 1) call up the management area theme and shade all management areas except E1, 2) call up the digital elevation (contour) theme

and shade all slopes over 40 percent, 3) call up the lodgepole risk theme and shade all areas but high risk lodgepole, and 4) call up the elk cover theme and shade areas of critical elk security including a two sight distance buffer. The remaining unshaded area is ground meeting the criteria for harvest on which this alternative can be developed.

The next step would be to overlay the existing and proposed road systems from the transportation theme. Other themes may be employed, such as soils, etc., if there is a concern or a need for their use in the development of an alternative. Once an alternative is developed on the terminal, you may wish to run it through the visual model if there are concerns on how it will appear from a given location. Modifications are easy to make and run back through the model. Other data, such as volume, acreage, etc., are easy to generate. Using INFORMS, a wide range of alternatives can be developed that are specific to criteria designed to address issues and concerns.

Estimating Effects

Based on the issues and concerns identified in the scoping process, selected resource response or impact models are used for each alternative to display the effects on a particular resource by the alternative being evaluated. The effects of an alternative on a resource are displayed in map or graphic and tabular form.

Evaluating Alternatives

Quantified graphic and tabular display of the effects of an alternative on a resource value that may be an issue or concern makes the job of the Interdisciplinary Team who must recommend an alternative a lot easier. Alternatives can easily be compared for their effect on a particular resource value. This in turn simplifies the job of weighing the benefits and impacts of the alternative being evaluated.

Identification of Preferred Alternatives

INFORMS aids the line officer or resource manager in the selection process by providing data on the effects of each alternative on resource values in map or graphic and tabular form that is displayed in common format.

The data displayed are generated by a common process that is repeatable, and information used to generate the data is of the same quality standards.

The deciding official can play "what if" if not completely satisfied with a recommended alternative and modify or refine an alternative and see what changes in effects on resource values are caused by the modification. Also, if an issue arises that is not addressed by an alternative, it is easy to develop a new alternative that addresses that issue. The data on effects make the process of documenting the rationale for a decision in a Decision Notice much easier.

Monitoring

INFORMS aids the resource manager in monitoring of a project because the process used to estimate effects is repeatable and the intermediate steps are visible and documented. If monitoring shows predicted effects are off from what is actually experienced, then the parameters of the model can be changed to more accurately reflect actual response.

SUMMARY

INFORMS can be used to help resolve complex natural resource problems more easily and efficiently, without requiring resource managers to become tool experts. By integrating models that simulate ecosystem interactions, managers were able to gain a better understanding of the interrelationships of the resources. With the increased speed and repeatability of INFORMS, managers "fine tuned" their decisionmaking. Designed primarily as an integrating shell, INFORMS assumes technology will continue to evolve, and allows for adaptation - an important feature.

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~~CASE HISTORY~~: NORTHERN REGION FOREST SERVICE EASTSIDE ZONE--MOUNTAIN PINE BEETLE CONSIDERATIONS

Richard J. Call

ABSTRACT: In the fall of 1985, personnel assigned to the Three Forest Timber Zone recognized the need for a coordinated strategy for responding to the mountain pine beetle threat in the Deerlodge, Lewis & Clark, and Helena National Forests. A task force was implemented which developed six alternatives. The three Forest Supervisors selected an alternative which places emphasis on harvesting green lodgepole pine while retaining the timber sales program at Forest Plan levels. The selected alternative offers maximum flexibility for adjusting programs between Ranger Districts, concentrating on infestation areas and areas of high risk.

During the fall of 1985, it became increasingly apparent that a three-forest strategy was needed for responding to the threat of a mountain pine beetle (MPB) attack in the suspectible stands on the Deerlodge, Helena, and Lewis & Clark National Forests. A zone-wide task force consisting of three District Rangers and three silviculturists from the zone, plus personnel from the Flathead Forest and from the Regional Office, was assigned the duty of assessing the potential of a MPB attack and preparing a report which would provide some alternatives for response. The need for a report and a coordinated strategy was prompted by the following perceptions:

* Hot spotting - each Forest appeared to be responding to the isolated outbreaks in an individual manner. There appeared to be no broad overview being looked at across the Three Forest Zone, and no attempt was being made to develop a consistent zone wide response.

* Organizational changes - several recent arrivals to the zone timber organization were reassigned from forests in the Forest Service Northern Region where MPB epidemics were in process. Experiences on these forests heightened an awareness of the potential for a MPB attack.

* The Draft Forest Plans for each Forest provided good direction to harvest old-growth lodgepole and ponderosa pine ahead of a MPB attack.

* A recent silviculture review on the Lewis & Clark Forest highlighted the potential for a MPB attack.

The objectives of the MPB Task Force were as follows:

* Describe the problem.

* Gather necessary data.

* Develop a range of alternatives.

* Present a report to the three Forest Management Teams.

Data gathering began by identifying mature and overmature lodgepole pine and ponderosa pine types on old, but available, timber type maps (1960's vintage). Specifically, the high-risk and moderate-risk stands were identified on overlay material. The overlays were then compared to the Draft Forest Plan maps which highlighted those stands in the suitable timber base on each Forest. Estimates were then developed of the acreage on each Forest of high risk and moderate risk stands.

A series of overlays were then prepared which showed MPB attacks on each Forest for the period 1976 through 1985. Projections were then made of where the MPB could reasonably be expected to move in the next 10- to 15-year period. These projections were transferred to forest plan maps, which became the basis for further estimates of the volume and value of the timber expected to be killed by the MPB.

Using available subcompartment maps showing P.I. type and forest strata, mortality predictions were developed using the INDIDS model, which predicts 10-year losses for stands within or adjacent to active infestations. Estimates of stumpage values were assigned to the projected losses so that a zone-wide potential loss calculation could be obtained.

Paper presented at the Symposium on the Management of Lodgepole Pine to Minimize Losses to the Mountain Pine Beetle, Kalispell, MT, July 12-14, 1988.

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The following table shows the potential volume loss of lodgepole pine (LPP) and ponderosa pine (PP) during the next decade for each Forest in the Three Forest Zone.

Potential Loss Calculation

	Allocation To TM (Acres)	High Risk LPP/PP (Acres)	Potential Loss (MMBF)
Deerlodge	352,000	208,000 (LPP)	1,067
L & C	282,000	137,000 (LPP) 6,000 (PP)	719 (LPP) 35 (PP)
Helena	251,000	113,000 (LPP)	791
Total	885,000	458,000 (LPP) 6,000 (PP)	2,577 (LPP) 35 (PP)

Using the available information, the MPB Task Force developed six alternatives for response to the potential MPB attack.

Alternative 1 - Continue existing direction as provided in the three draft forest plans. Approximately 70 percent to 80 percent of regulated harvest would be implemented in the high-risk lodgepole pine and ponderosa pine types.

Alternative 2 - Concentrate zone harvest almost exclusively (95 percent plus) in LPP/PP timber types while being responsive to identified minimum industry requirements for other species and non-sawlog components. Retain district and forest program levels.

Alternative 3 - Concentrate harvest in LPP/PP types. Adjust district level programs as needed to salvage major outbreaks and to develop and harvest large areas of high risk LPP. Retain forest level programs. Emphasize development of high risk stands using the capitol investment program.

Alternative 4 - Concentrate harvest in LPP/PP types. Accelerate harvest of green volume during the early years of the next decade. Reduce harvest accordingly during the later part of the decade so that decade allowable sell quantity is maintained for each forest within the zone.

Alternative 5 - Concentrate harvest in LPP/PP types. Accelerate harvest of green volume on each forest for the entire decade. Exceed ASQ on each forest by approximately 50 percent. Adjust final forest plans to reflect major changes in harvest levels.

Alternative 6 - Concentrate harvest in LPP/PP types. Consider the three forest's ASQ as one timber program rather than individual forest or district programs. Implement the zone program with the objectives of developing and placing under contract large areas of high risk LPP, and salvaging major outbreaks. Do not accelerate harvest.

In September, 1986, the three Forest Supervisors met in Helena to discuss and reach agreement on a coordinated response to the threat of a MPB infestation. The group discussed the MPB Task Force Report and examined the 1986 MPB survey reports which had just been completed for each Forest.

The Forest Supervisors adopted Alternative 3. The primary reasons for selection of Alternative 3 were that it permitted final forest plans to be completed without major overhaul; it kept response to the threat in line with the actual rate of infestation; it could be accomplished with existing funding and personnel; and finally Alternative 3 harvest levels could be accelerated through forest amendments if the need arose in the future.

The Forest Supervisors sent the following seven step process to the District Rangers as direction for implementing Alternative 3:

1. Annually, identify high-risk stands
2. Prioritize high-risk stands
3. Determine road access needs
4. Translate into timber sale proposals
5. Make appropriate adjustments to the 10-year plans
6. Report 10-year plans to Forest Supervisor by March 1, annually
7. Timber zone consolidate into three forest programs

In summary, preparation of the MPB Task Force Report accomplished three major objectives: it pulled a substantial amount of existing data into one report; it raised the level of awareness of Line and Staff Officers within the zone to the threat of a MPB infestation; and, lastly, it has allowed the Three Forest Zone to proceed with harvest and development plans in a coordinated manner.

SILVICULTURAL STRATEGIES TO MINIMIZE MOUNTAIN PINE BEETLE LOSSES--AN OVERVIEW

James H. VanDenburg

ABSTRACT: A mountain pine beetle epidemic started in the Flathead National Forest in 1975. An environmental analysis was completed in 1979. This paper reviews the chosen alternative, silvicultural guidelines, and findings after 9 years.

INTRODUCTION

The mountain pine beetle epidemic in the Flathead National Forest actually started in Glacier National Park in 1972. By 1975 it had expanded to the Glacier View Ranger District adjacent to the Park on the west. From there it spread farther west to the Tally Lake Ranger District. In 1979, the Forest prepared an Environmental Analysis of the MPB situation it found itself in.

E.A. REPORT

The chosen alternative called for a revision of the Flathead Forest 5-year timber sale plan. This encompassed the following:

The Tally Lake District will compress a previously scheduled 6-year program into 3 years, FY 1980-82. The District has inventoried 320 million board feet of high-risk lodgepole pine, of which approximately 160 million board feet is to be programmed for sell during the 3-year period. Other Districts and engineering personnel and resources will be assigned to Tally Lake projects in order to maintain a balanced Forest workload. The District will assure access is planned to all high-risk stands.

The Swan Lake District sell program will also be directed primarily to high-risk lodgepole pine. This District has substantial areas of high-risk lodgepole pine currently under contract, or programmed for sell in the ensuing 5-year program. Additional surveys will be conducted in the 1979 field season to assess the potential for rapid buildup of the mountain pine beetle in the District. Insect and disease funds are available to assist in this work. Special emphasis will be directed toward the Island Unit west of Kalispell, which is closest to the infection source. The District will work closely with Burlington Northern Railroad and the State of Montana where their lands are intermingled with National Forest lands. The District will assure access is planned and developed to all high-risk stands.

The Glacier View District will continue cleanup and salvage of infested lodgepole pine. District lodgepole volumes are expected to drop off substantially after FY 1979. The epidiemic stage will have essentially subsided on available commercial forest land.

The remaining two Flathead Ranger Districts, Hungry Horse and Spotted Bear, will conduct surveys during the 1979 field season to determine the status of infestations in their Districts. Insect and disease funds are available to assist in this work. Preplanning for access and harvest should proceed as the situation warrants.

With the chosen alternative in place, the task fell to the Districts to implement the direction. Silvicultural guidance provided by the E.A. was as follows:

1. Prioritize treatment of lodgepole pine stands to those of most imminent susceptibility to insect attack. Utilize the mountain pine beetle risk inventories and incorporate the factor of stress in predisposing trees previously non-susceptible to epidemic mountain pine beetle populations to successful attack and the resultant high brood production that key epidemics.

2. When feasible and sound, silvicultural regeneration methods other than clearcutting should be used. This guideline is compatible with the NFMA and Forest policy, and will assist development of mixed species stands and reduce certain resource impacts.

3. Attempt to obtain a diversity of timber species, avoiding where possible regeneration to pure lodgepole pine stands. Artificial regeneration may be necessary in some situations to assist this requirement.

4. In compliance with laws and regulations, and to reduce potential for adverse resource impacts, ensure that regeneration cuts are fully restocked within a 5-year period following harvest.

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5. Long-term silvicultural prescriptions should recognize the importance of creating lodgepole pine age class diversity by varying rotation lengths within legal constraints and timber management plan guidelines.

6. Silvicultural treatments should be fully responsible to other resource management requirements and constraints itemized in this section.

DISCUSSION

Silvicultural Management Systems that have been employed by the Districts over the last 9 years to combat the MPB epidemic are a variety of harvest treatments aimed at capturing as much green lodgepole as possible within existing constraints of other resources. These treatments included clearcutting, seed tree, shelterwood, sanitation, salvage, and partial cutting. Obviously, as most high-risk stands were predominately pure lodgepole pine, or nearly so, clearcutting became the most frequently used harvest method. Where three to 10 relatively good seed trees were available, usually western larch, the seed tree method was employed. Occasionally, shelterwood, sanitation, or salvage were used where those systems were appropriate. They usually occurred in mixed stands where large lodgepole pine were desirable to harvest and when a manageable stand could be left. Within the last several years, some partial cutting in lodgepole stands to a residual basal area of around 100 square feet was used. These stands were in areas where other cutting methods could not be used effectively due to other resource constraints.

SUMMARY

Looking back at the last 9 years of dealing with the mountain pine beetle in the Flathead Forest, we have realized a number of things that can be shared with others facing similar conditions.

1. Consider lodgepole pine stands for management as soon as possible. The idea of "use it or lose it" applies with mature lodgepole pine more than some other longer lived species.

2. Stand exam information can be invaluable in helping determine priorities for treatment of lodgepole pine, and risk rating models can be run from stand exam data.

3. After risk rating, diagnosis, and prioritizing lodgepole stands, silviculture prescriptions can be prepared.

4. Clearcutting will likely be the harvest method most utilized due to the fact that the highest priority stands for removal are those which contain the largest volume of green lodgepole pine.

5. Many clearcuts will exceed 40 acres either by themselves or when considered with adjacent cutover areas. This is a temporary condition until management objectives are met and areas are no longer considered openings. In timber management areas, this is when the areas are certified as stocked.

6. The Flathead Forest considered the harvest of green lodgepole pine preferable to harvesting dead lodgepole, or leaving dead standing. However, at best, only 80 percent (or less) of lodgepole stands can be harvested in a given area for various reasons.

7. Consideration should be given to those stands which cannot be harvested for various reasons. These stands should also be prioritized by their value to other resources. Remember, dead lodgepole pine does not provide cover for wildlife or pump water for the watershed. However, existing understories may.

8. Consider that dead lodgepole left will eventually fall down, impede wildlife use and movement, and create a fire hazard. All in all, these areas likely will not meet management objectives for some time.

9. Regeneration should be well planned and prompt. In many stands, lodgepole pine will regenerate naturally if cones are left on the ground and there is adequate site preparation. Species diversity should be considered on an area basis, so that future stands will have desirable management opportunities. The area should have species diversity; individual stands may not. Trying to build species diversity into every stand has proven expensive and unnecessary.

10. In the future, stocking control and other intensive management should prevent the mountain pine beetle from impacting the Flathead Forest in the manner that it has in the past.

PARTIAL CUTTING (SANITATION THINNING) TO REDUCE MOUNTAIN PINE BEETLE-CAUSED MORTALITY

Kenneth E. Gibson

ABSTRACT: Data collected over the past decade have shown partial cutting to be a viable management alternative in lodgepole pine stands threatened by mountain pine beetle. Now this strategy is being used operationally as an alternative to clearcutting. Criteria for selecting suitable stands are included.

INTRODUCTION

As has been pointed out repeatedly in this symposium, the mountain pine beetle (MPB) and lodgepole pine (LPP) stands have an extremely long history of interaction. In a purely ecological setting, that interaction would have to be viewed as a mutally beneficial one. Despite the host tree being killed, in its death it sets the stage for a stand-replacing fire--often thought to be necessary because of cone serotiny exhibited by LPP. Now, however, we find ourselves in direct competition with MPB for the resources and amenities found in LPP forests. Suddenly, terms such as "loss," "catastrophy," and "disaster" are associated with the MPB/LPP relationship.

For decades, we have diligently recorded locations of outbreaks, cataloged mortality rates, and planned strategies to combat the MPB menace. Beginning in the 1920's and continuing to as recently as 15 years ago, major Forest Service efforts were directed at killing beetles (Klein 1978). Indeed, some suggest--and I'm not taking issue with the notion--that this is still a viable strategy under certain sets of conditions. Amman and Baker (1972) pointed out as early as 1972 that where efforts to control MPB outbreaks are concentrated on the beetle and susceptible stand conditions remain, infestations will recur in those stands again and again until, ultimately, the effect on the stand will be the same--though prolonged.

Though we are sometimes slow to get the message Mother Nature is trying to tell us, with diligence we usually come through! Such was the case in our efforts to curb mortality attributed to the MPB. By the mid-1970's, we finally came to realize that the only truly successful and long-term method of combating the beetle was to reduce its opportunity to increase to outbreak proportions by removing or changing susceptible stand conditions. Unfortunately, because of an array of political, social, and economic factors--and very few biological ones--it has taken us nearly a decade and a half to develop, demonstrate, and implement strategies useful in forestalling losses to MPB.

MANAGEMENT RECOMMENDATIONS

Speakers at this symposium have described, or will, management strategies for various stand conditions which, if implemented, would help reduce or eliminate beetle-caused mortality. Recommendations vary with age and stand conditions--whether stands are pure LPP, immature, mature, or overmature; or mixed species stands in those same categories. Most successful recommendations propose the creation of age, size, or species mosaics to eliminate large expanses of susceptible host material. The wisdom of those recommendations has been proven over the last decade as we have responded to impacts or threats from MPB.

Most often, the silvicultural recommendation of choice, particularly where LPP is imminently susceptible to beetle depredations, is stand removal. Because of LPP's short-lived nature and the relatively high expense of harvesting smaller diameter logs, clearcutting is frequently the most reasonable alternative. Now, however, in many areas--management units, primary and secondary drainages, compartments and stands--losses, or actions taken to reduce threatened losses, have resulted in the need to consider alternatives to clearcutting.

ALTERNATIVES TO CLEARCUTTING

Beginning about 1976, alternatives to clearcutting were being proposed and tested in LPP stands in the western United States. Cahill (1978) reported on work done in Colorado, Hamel (1978) described early efforts in southwestern Montana, and Cole et al. (1983) detailed partial cutting strategies in Wyoming. Those promising results led to the development of demonstration areas on the Kootenai

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and Lolo National Forests in Montana in 1978. Results of those demonstrations have recently been reported by McGregor et al. (1987). With their permission, I would like to briefly summarize their findings:

> On each Forest, three levels of diameter limit cutting--all trees over 7 inches d.b.h., all trees over 10 inches d.b.h., and all trees over 12 inches d.b.h.; and three levels of spaced thinnings--residual stocking of 80 sq. ft./acre, 100 sq. ft./acre, and 120 sq. ft./acre--were installed. Unthinned check areas on each Forest were also monitored. Cutting began in 1978 and was completed in 1980. At the time, both areas were experiencing extremely heavy MPB infestations. Evaluations in 1985 showed losses to MPB were greatly reduced in the partial cut areas--regardless of type--when compared with unthinned stands. Numerical results for the Kootenai study areas showed total average mortality were as follows: 6 percent in the 10-inch cuts, 8.6 percent in 12-inch cuts, 7.8 percent in 80 BA cuts, 4.0 percent in 100 BA cuts, 38.6 percent in 120 BA cuts, and 93.8 percent in unthinned checks. Lolo study areas showed the following: 6.9 percent in the 10-inch cuts, 17.1 percent in the 12-inch cuts, 6.7 percent in the 80 BA cuts, 6.0 percent in the 100 BA cuts, 13.1 percent in 120 BA cuts, and 73.1 percent in unthinned checks. All in all, results most impressively document the effects of partial cutting.

Follow-up studies have shown immediate effects are realized by altering stand conditions to ones less favorable to the beetle (Bartos and Amman, in press). Long-term benefits are effected by a growth response in released trees. In summary, viability of partial cutting as an alternative to regeneration harvests has been clearly demonstrated--when the only other option is unacceptable beetle-caused mortality.

OPERATIONAL PARTIAL CUTTING

Beginning in 1982, management plans were developed for LPP stands threatened by MPB on the Swan Lake Ranger District, Flathead National Forest. Beetle populations had begun to increase markedly on the District in 1981. Within the next 2 to 3 years, clearcutting in response to beetle threats had resulted in hydrologic limits being nearly reached in some drainages. In addition, essential big game cover was also being seriously depleted. Despite the best efforts, additional LPP stands were being threatened by ever-increasing beetle infestations.

Basing prescription development on preliminary results of the Lolo and Kootenai demonstration areas, Bollenbacher (pers. comm.) devised sanitation thinning regimes for three stands in the District. These were stands almost certain of being infested, but ones for which clearcutting was not desirable.

Prior to thinning, stands ranged from 164 to 183 square feet of basal area. They were thinned to 92, 112, and 143 square feet--two in July 1985, the other in September 1986. Because larger, more vigorous trees were left, average stand diameter increased from 7-8 inches, to 8-9.5 inches. Following beetle flight in 1986, adjacent uncut areas had experienced beetle attacks ranging from 20 to 53 percent of the stand. In the three thinned stands, beetle-caused mortality was zero, 5 percent and 16 percent. The latter was immediately adjacent to the most heavily infested uncut stand and may have been under attack at the time it was being cut. Evaluations made after beetle flight in 1987 showed infestations continuing in all adjacent areas while no new attacks were observed in any of the thinned stands (Gibson 1988).

Following his experiences with sanitation thinning, Bollenbacher has developed guidelines which can assist the land manager in evaluating the practicality of that strategy for a particular set of conditions. They are:

1. Site productivity: Better sites will add to the likelihood of increased growth and vigor of leave trees.

2. Slope: As a rule, treat stands on tractor ground of less than 35 percent to limit residual stand damage.

3. Average stand diameter: Choose stands where average d.b.h. exceeds 9 inches with less than 350 trees over 5 inches d.b.h. per acre. Such stands will be more economical to log with less residual damage.

4. Age: Stands should be between 60 and 125 years old.

5. Current stocking: Stands should have at least 130 sq. ft./acre basal area to make an economical logging opportunity.

6. Elevation: Consider stands where longer growing seasons translate to higher MPB risk. For northwestern Montana, that is 6,000 feet elevation or less.

7. Wind firmness: Choose most sheltered slope position. Refer to Alexander's (1975) risk categories.

8. Present MPB status: Stands should have present infestation rate of 10 percent or less.

9. Tree vigor: Candidate stands should have crop trees with live crown ratio of 30 percent or greater.

10. Other resource objectives: Consider only those stands where other resource objectives may not be met through regeneration harvesting (Bollenbacher and Gibson 1986).

CONCLUSIONS

In summary, research, demonstrations, and operational programs have shown partial cutting to be a sound silvicultural alternative in LPP stands threatened by MPB. As noted, that is not to suggest that partial cutting is the preferred alternative in every situation; rather, it can be used to great advantage when all resource considerations dictate clearcutting is not appropriate. Given the changes wrought by MPB in LPP stands in the past decade, and the susceptible stands remaining, that may occur more and more often before current infestations have run their course.

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WHY PARTIAL CUTTING IN LODGEPOLE PINE STANDS REDUCES LOSSES TO MOUNTAIN PINE BEETLE

Gene D. Amman

ABSTRACT: Thinning stands of lodgepole pine (Pinus contorta Douglas var. latifolia Engelmann) greatly minimized tree losses to mountain pine beetles (Dendroctonus ponderosae Hopkins). Although losses were reduced immediately following thinning, trees did not respond with increased growth until the second year after thinning. Tree losses in partial cut stands were more closely related to large tree diameter than to tree vigor indices.

Beetles were trapped in thinned stands for several years after thinnings were completed but were infesting only a few of the residual trees. The altered microclimate of the stands is suspected of being the factor most likely affecting beetle behavior.

Thinning lodgepole pine stands increased light intensity, wind movement, insolation, and temperature. Temperatures on the south exposure of tree trunks and of soil were significantly higher in thinned than unthinned stands.

INTRODUCTION

Silvicultural methods to reduce losses from bark beetles traditionally are aimed at decreasing tree competition and increasing tree vigor (Graham and Knight 1965; Keen 1958), thus making the trees better able to repel attacking beetles with copious resin flow (Reid and others 1967). To test partial cutting of mature lodgepole pine (Pinus contorta Douglas var. latifolia Engelmann) stands to reduce tree losses to mountain pine beetles (Dendroctonus ponderosae Hopkins [Coleoptera: Scolytidae]) (MPB), large-diameter trees were removed from stands on Bureau of Land Management lands near Granby, CO, in 1972 (Cahill 1978). Large-diameter trees favor high beetle production because they have thicker phloem (food of developing larvae) than that found in small-diameter trees (Amman 1972). This treatment resulted in losses to MPB of 1 to 2 percent, whereas tree losses in unthinned stands were 39 percent. Diameter limit cuts on the Gallatin National Forest near West Yellowstone, MT, showed similar reductions in tree losses to MPB (Hamel 1978). Partial cutting tests on the Shoshone National Forest in northwest Wyoming, consisting of (1) diameter limit thinnings that removed all trees 7, 10, or 12 inches and larger d.b.h., (2) spaced thinnings leaving the 50 best trees per acre, and (3) untreated check stands, resulted in losses of less than 1 percent of trees in partial cut stands, compared to 4 percent in check stands the first year following cutting (Cole and others 1983). Five years after the partial cuts were made on the Shoshone National Forest, tree losses to MPB ranged between 0.3 to 7 percent in partial cut stands, compared to 27 percent in unthinned check stands (fig. 1) (Amman and others 1988a). Partial cutting tests on the Kootenai and Lolo National Forests in northwest Montana included (1) diameter limit thinnings that removed either all trees 10 or 12 inches and larger d.b.h., (2) spaced thinnings that left residual basal areas of 80, 100, or 120 ft^2 BA/a, and (3) check stands. Five years after these partial

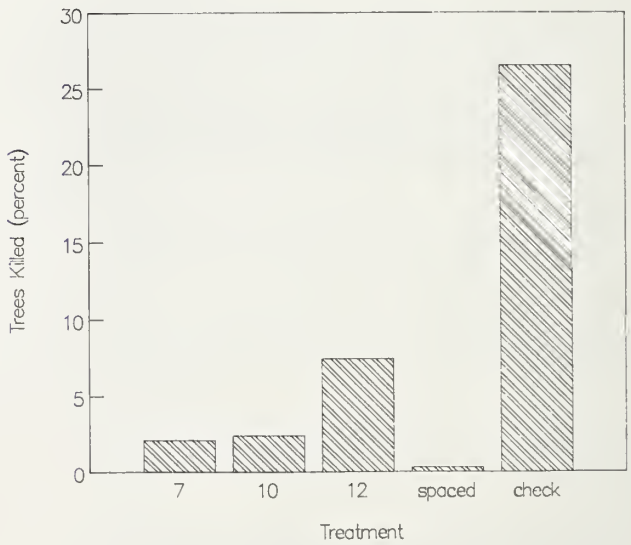

Figure 1--Percent lodgepole pine killed by mountain pine beetles in different partial cutting treatments, Shoshone National Forest, WY, 1981 to 1985 (from Amman and others 1988a). Treatments indicate diameter limit cuts in which all trees 7, 10 or 12 inches and larger d.b.h. were removed; spaced thinnings in which the 50 best trees per acre remained; and untreated check.

Paper presented at the Symposium on the Management of Lodgepole Pine to Minimize Losses to Mountain Pine Beetle, Kalispell, MT, July 12-14, 1988.

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cuts were made, tree losses were less than 17 percent in all partial cut stands except those that left 120 ft^2 BA/a, where losses were 38 percent. Losses were 73 and 94 percent, respectively, in the Kootenai and Lolo check stands (fig. 2) (McGregor and others 1987). Lodgepole pine losses to MPB also were much reduced in thinnings established 7 to 15 years prior to evaluation of tree losses to MPB in Oregon (Mitchell and others 1983b). Tree losses in the Oregon thinnings averaged 9 percent, compared to 19 percent in unthinned check stands.

Following partial cutting of lodgepole pine stands on the Kootenai, Lolo, and Shoshone National Forests, observations were made of: (1) response of MPB determined by trapping the beetles, and (2) changes in radial growth and vigor indices of residual trees in relation to susceptibility of MPB infestation. A third item, differences in microclimate of thinned and unthinned stands as they relate to MPB infestation, was determined on the Wasatch National Forest in northeastern Utah.

BEETLE RESPONSE TO PARTIAL CUT STANDS

Little is known about the influence of stand environment on the flight and host selection behavior of MPB. What is known has been documented during outbreaks in uncut stands. The fact that the beetle kills the largest diameter lodgepole pines remaining in infested stands during successive years of an outbreak is well documented (Cole and Amman 1969; Hopping and Beall 1948). This observation agrees with laboratory measures of host selection behavior that show the beetle is attracted to large, dark silhouettes (Shepherd 1966) and vertical cylinders (Gray and others 1972; Schönherr 1976). The beetle's apparent preference for large-diameter trees is such that it will infest these trees even when intermingled smaller trees are baited with components of the beetle's aggregative pheromone (Rasmussen 1974).

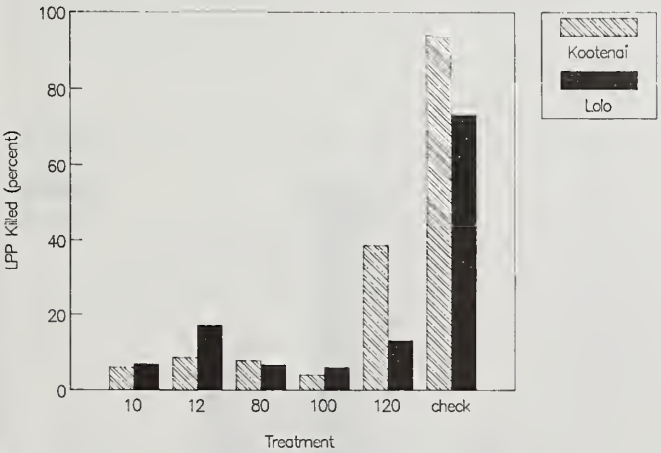

Figure 2--Percent lodgepole pine (LPP) killed by mountain pine beetles in different partial cutting treatments, Kootenai and Lolo National Forests, MT, 1980 to 1984 (from McGregor and others 1987). Treatments indicate diameter limit cuts in which all trees 10 or 12 inches and larger d.b.h. were removed, spaced thinnings leaving 80, 100, or 120 ft^2 BA/a, and untreated check.

To study how stand density affects the dispersion of MPB in partial cut stands of lodgepole pine, omnidirectional passive barrier traps were used to monitor numbers of MPB in flight (Schmitz and others 1980; Schmitz and others, in press). Traps consisted of two clear Plexiglas panels with funnels and containers at the base of the panels to entrap the beetles that flew into the panels. Each trap had a total intercepting surface above the funnels of 7.75 ft^2 (Schmitz 1984). Three of these traps were hung on a single nylon cord supported on a horizontal line between the crowns of two adjacent trees. Traps on the line were positioned so they corresponded to midcrown, midbole, and about 6 ft above ground (fig. 3). Two such lines were hung in each stand monitored for beetle flight.

In earlier work on the Gallatin National Forest near West Yellowstone, MT, Schmitz and others (1980) found that most MPB flew in the midbole area. Beetles were caught with about equal frequency in thinned and unthinned stands, but more trees were infested in unthinned stands (Hamel 1978). Numbers of beetles caught among treatments after 4 years on the Kootenai and Lolo National Forests were significantly different

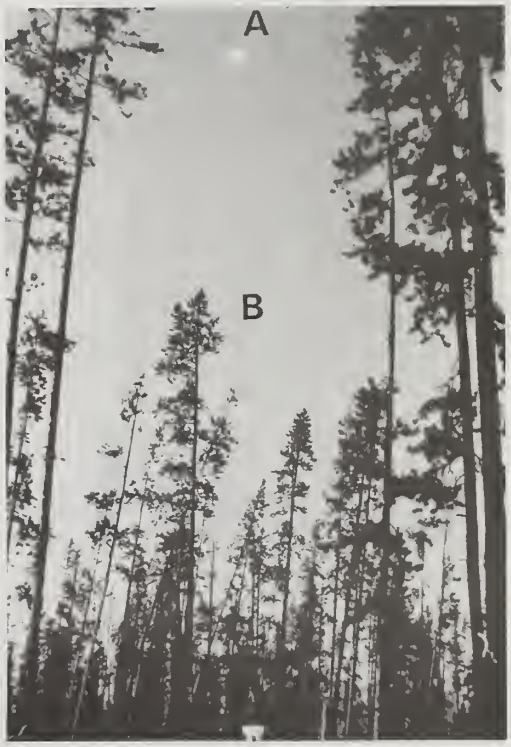

Figure 3--Omnidirectional passive barrier traps used to catch flying beetles: (A) horizontal support line with pulley for attachment of vertical line; (B) vertical line used to raise and lower traps, with three traps attached.

among partial cutting treatments (fig. 4). The treatments separated into two groups. Group one had the fewest beetles and included stands having 100 ft^2 BA/a of residual basal area and the 10-inch diameter limit cut. Group two consisted of the 120 ft^2 BA/a and the check stands, which had the greatest tree densities. The other two treatments, consisting of 80 ft^2 BA/a and the 12-inch diameter limit cut, did not differ significantly from group one or group two. In general, the greatest numbers of beetles were trapped in group two stands, and the greatest numbers of trees were killed in these stands (Schmitz and others, in press). Comparison of percentages of residual trees killed with MPB trapped between thinned and unthinned stands revealed the percentage of trees killed in the thinned treatments was proportionately less than might have been expected, based on the number of MPB trapped. Overall, the ratio of estimated MPB in flight per tree killed was greater in thinned stands than in unthinned check stands (fig. 5). As on the Gallatin National Forest (Schmitz and others 1980), most MPB were caught in midbole traps (fig. 6) (Schmitz and others, in press). The loss of fewer trees in thinned stands than in unthinned stands proportional to the numbers of flying beetles suggests that many beetles were not stopping to infest trees in thinned stands.

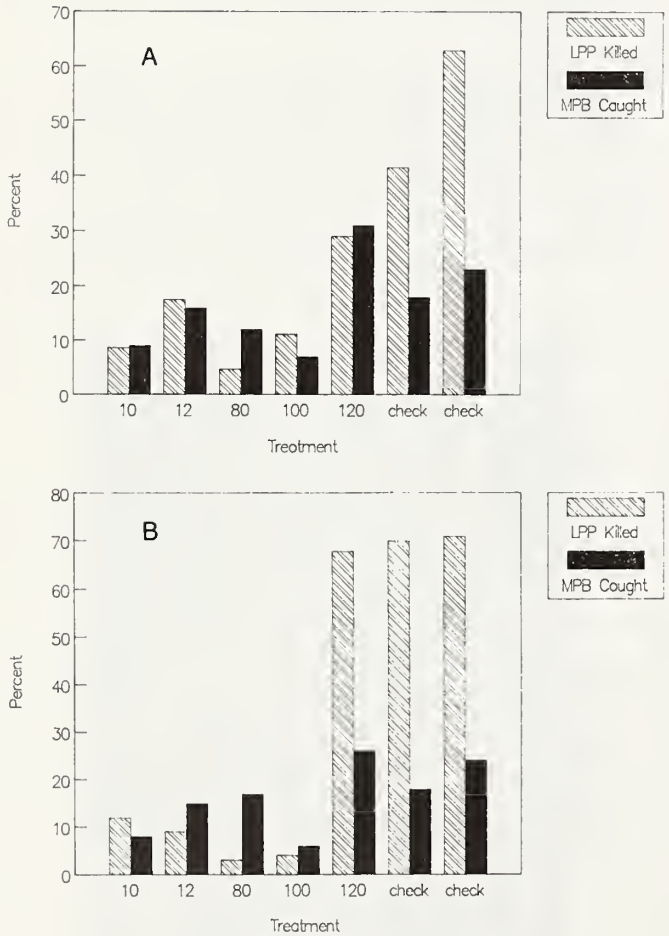

Figure 4--Percentage of total mountain pine beetles (MPB) caught per treatment compared with percentage of residual lodgepole pine (LPP) killed per treatment following thinning in the (A) Lolo and (B) Kootenai National Forests, MT, 1980 to 1983 (from Schmitz and others, in press). Treatments indicate diameter limit cuts in which all trees 10 or 12 inches and larger d.b.h. were removed, spaced thinnings leaving 80, 100, or 120 ft^2 BA/a, and untreated check.

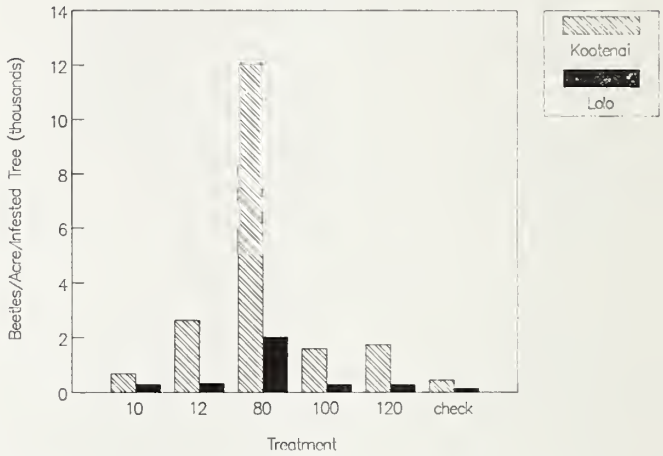

Figure 5--Ratio of estimated inflight beetles (MPB) per acre for each tree killed by mountain pine beetles in partial cutting treatments on the Kootenai and Lolo National Forests, MT (from Schmitz and others, in press). Treatments indicate diameter limit cuts in which all trees 10 or 12 inches and larger d.b.h. were removed, spaced thinnings leaving 80, 100, or 120 ft^2 BA/a, and untreated check.

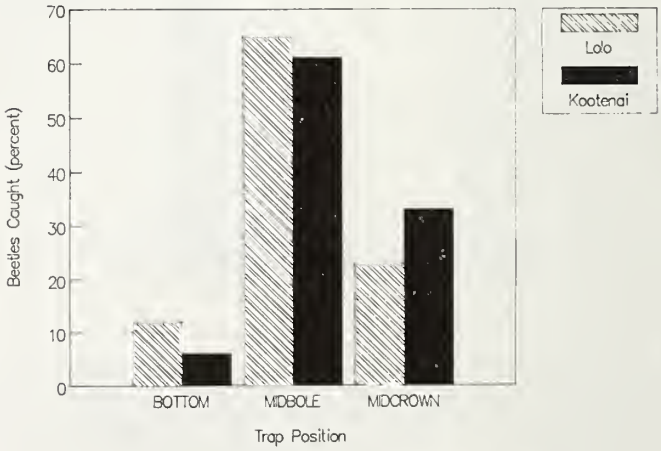

Figure 6--Percentage of mountain pine beetles (MPB) caught by trap position in the Lolo and Kootenai National Forests, MT, 1980 to 1983 (from Schmitz and others, in press).

GROWTH RESPONSE FOLLOWING PARTIAL CUTTING

Radial growth of residual trees in the Kootenai stands was slightly reduced or about the same in 1980 as in 1979, the year of most thinnings. Only trees in the 80 and 100 ft^2 BA/a treatments increased in growth the first year following thinning. Most stands showed increasing growth trends starting in 1981 (fig. 7) (Amman and others 1988b).

The trend in radial growth in the Lolo stands, including untreated checks, also declined the first year following thinning, except for the 100 ft^2 BA/a treatment, which increased slightly (fig. 8). Radial growth for most stands, including check stands, although not quite as large as in the Kootenai stands, showed an upward trend from 1981 through 1984, with the exception of a sharp decline in 1982.

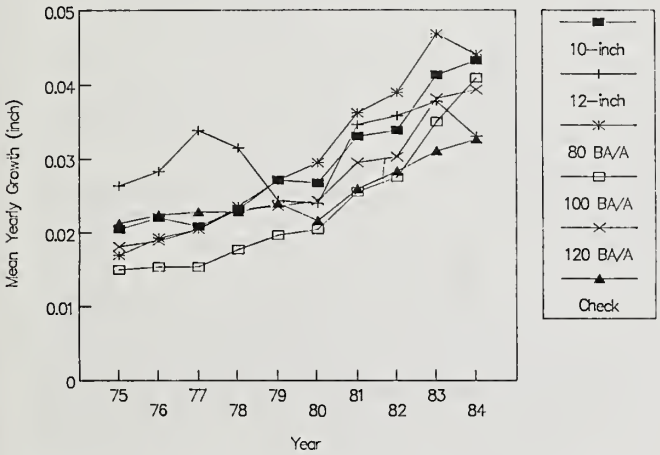

Figure 7--Mean annual growth (radial) of lodgepole pine in partial cutting treatments applied in 1979 to reduce tree losses to mountain pine beetle, Kootenai National Forest, MT (from Amman and others 1988b).

In the Shoshone National Forest, significant radial growth occurred following thinning in 1979 and 1980 (fig. 9). None of the treatments showed decline in growth following thinning, although a slight flattening of the growth curve occurred for the 7-inch and 10-inch diameter limit cuts between 1979 and 1980. Check stands showed a decline in growth during this period. Trees in all treatments, including the checks, had substantial live crown, with averages ranging between 46 and 63 percent of total tree height. However, only the check stands did not respond with a significant increase in radial growth, but the trend in growth was up. Apparently, reductions in numbers of trees caused by MPB were not large enough to provide as rapid growth response as partial cutting treatments on the Kootenai and Lolo National Forests. Extensive tree mortality in check stands on the Kootenai and Lolo resulted in significant growth response of residual trees.

Five years after partial cuts were made on the Kootenai and Lolo National Forests, none of the stands were considered vigorous. Lodgepole pines, with average ages of 102 and 76 years on the Kootenai and Lolo, respectively, and 100 on the Shoshone, are past the age when maximum resin response to MPB infestation could be expected (Shrimpton 1973). Trees were growing at a slow rate prior to and for several years after thinnings were completed. Although average radial growth of trees in some stands increased 100 percent by the fourth year following thinning, this was only an increase of 0.02 inch.

The first year following thinning, most stands showed a slight reduction in growth. Because thinning tends to improve moisture availability in thinned stands, Donner and Running (1986) suggested that a negative growth response following thinning is probably caused by reduced

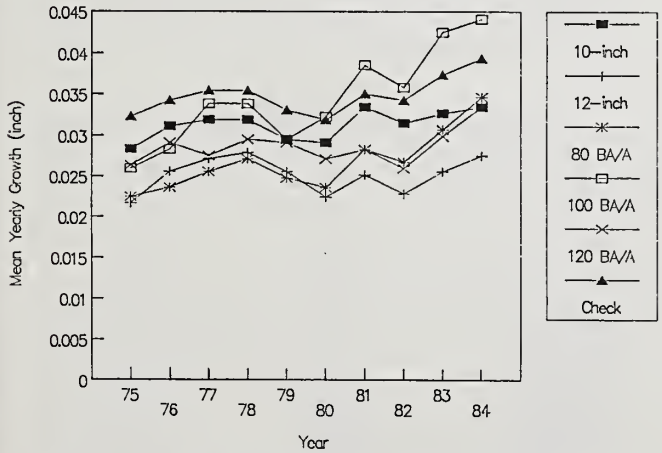

Figure 8--Mean annual growth (radial) of lodgepole pine in partial cutting treatments applied in 1979 to reduce tree losses to mountain pine beetle, Lolo National Forest, MT (from Amman and others 1988b).

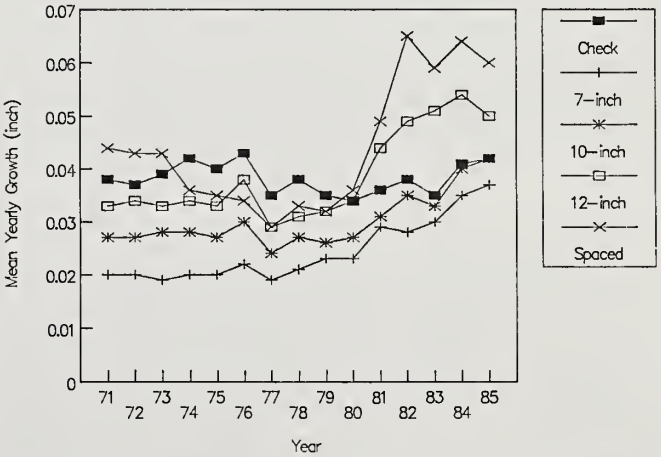

Figure 9--Mean annual growth (radial) of lodgepole pine in partial cutting treatments applied in 1979 and 1980, Shoshone National Forest, WY (from Amman and others 1988a).

photosynthetic capacity related to loss of shade leaves after exposure to full sunlight. During this first year (1980), growth probably was limited to root and shoot growth because radial trunk growth is the last to occur (Waring 1983). An increase in radial growth started the second year following thinning in all stands, including checks, on the Kootenai, Lolo, and Shoshone, probably because of increased moisture following thinning. Increased diameter growth following thinning can be expected in nearly all ages and densities of lodgepole stands that have not lost their physiological capability to recover from stagnation (Cole 1975). Reduced tree losses to MPB following partial cutting should not have occurred on the basis of tree growth because growth was so small.

TREE VIGOR FOLLOWING PARTIAL CUTTING

Several tree and stand characteristics have been related to susceptibility of MPB infestation (Amman and others 1977; Berryman 1978; Cole and McGregor 1983; Mahoney 1978; Safranyik and others 1974; Schenk and others 1980; Shrimpton 1973; Stuart 1984; Waring and Pitman 1980). Many of the variables measured for these methods are more appropriate for natural stands than for recent partial cut stands. For example, variables related to tree competition as a precursor to MPB infestation would be inappropriate, since thinning reduces numbers of trees below the level of intertree competition. These variables include crown competition factor (CCF) (Schenk and others 1980; Berryman 1978) and stand density index (SDI) (Anhold and Jenkins 1987). The resinous response of trees to inoculation of blue-staining fungi (Ceratocystis clavigera [Robinson-Jeffrey and Davidson] Upadhyay) (Raffa and Berryman 1982; Shrimpton 1973) also is inappropriate, since blue-stain inoculations did not distinguish lodgepole pine that were susceptible to MPB infestation in natural stands (Peterman 1977). Three tree characteristics that can be applied to thinned as well as natural stands are diameter at breast height (d.b.h.) (Amman and others 1977; Cole and McGregor 1983; Safranyik and others 1974; Stuart 1984), periodic growth ratio (PGR), which is the current 5 years of radial growth divided by the previous 5 years of radial growth (Mahoney 1978), and grams of wood produced per square meter of foliage (Mitchell and others 1983b). These three risk-rating methods were applied to trees in partial cuts on the Kootenai, Lolo, and Shoshone National Forests. Comparisons were made between the characteristics of trees killed by MPB and adjacent live trees, using analysis of variance (ANOVA) and discriminant analysis.

Discriminant analysis is a procedure that uses measurements on a series of characteristics to classify individuals into categories. Once a function has been developed to perform this, it can be used to classify individuals of unknown origin into the category to which they most likely belong. Diameter at breast height was found to be the most discriminating of the variables measured (table 1). PGR and grams of wood per square meter of foliage were larger in trees killed by MPB in half of the partial cuts, and larger in surviving trees in the other half of the partial cuts. Therefore, these characteristics were not useful in discriminating between susceptible and nonsusceptible trees in the partial cut stands (Amman and others 1988b). The discriminant function showed that 69.4 percent of live trees had characteristics of live trees, whereas 30.6 percent of live trees had characteristics of dead trees. In contrast, 75 percent of dead trees had characteristics of dead trees and 25 percent had characteristics more closely related to live trees (table 2). A large, squared distance between the means of the standardized value for the discriminant function indicates it is easy to discriminate between the groups. The squared distance is a function of the group means and the pooled variances and covariances of the variables (Afifi and Clark 1984). The pairwise squared distances, based on d.b.h., grams of wood, PGR, and leaf area, between live and MPB-killed

Table 1--Probability of >F for discriminant analysis

	One-way ANOVA				Multivariate
Treatment	DBH	Grams of wood	PGR	Leaf area	Wilk's Lambda
10-inch diam. limit	0.7092	0.7092	0.7092	0.7092	0.7092
12-inch diam. limit	0.0560	0.7013	0.7895	0.5273	0.1420
80 ft^2 BA/a	0.0001	0.0693	0.7320	0.0229	0.0001
100 ft^2 BA/a	0.0001	0.5823	0.0151	0.0292	0.0001
120 ft^2 BA/a	0.0001	0.7197	0.4789	0.0001	0.0001
Check	0.0787	0.4671	0.0303	0.2676	0.0448

Table 2--Classification of live and MPB-killed lodgepole pine by the discriminant function

Treatment	Tree condition	Live	Dead	Dead tree characteristics
		- - Percent - -		
10-inch diam. limit	Live	64.0	36.0	
	Dead	0.0	100.0	>DBH <GMS >PGR >LA
12-inch diam. limit	Live	71.4	28.6	
	Dead	39.2	60.8	>DBH >GMS >PGR >LA
80 ft^2 BA/a	Live	67.5	32.5	
	Dead	27.8	72.2	>DBH <GMS <PGR >LA
100 ft^2 BA/a	Live	74.3	25.7	
	Dead	13.8	86.2	>DBH >GMS <PGR >LA
120 ft^2 BA/a	Live	73.1	26.9	
	Dead	23.9	76.1	>DBH >GMS <PGR >LA
Check	Live	66.2	33.8	
	Dead	45.2	54.8	>DBH <GMS >PGR >LA
Average	Live	69.4	30.6	
	Dead	25.0	75.0	>DBH -- -- >LA

trees (table 3) showed greatest distances occurred in the spaced thinnings (80, 100, and 120 ft^2 BA/a) and least distance in the check stands. Distances in the diameter limit thinnings were intermediate, with the 12-inch diameter limit thinning having a value close to the check.

On the Shoshone National Forest, not enough trees were killed by MPB for comparisons to be made between characteristics of killed and surviving trees. However, observations on surviving trees show grams of wood produced per square meter of foliage was still well below the 100-g level dividing susceptible from nonsusceptible trees 5 years after partial cuts were made (Amman and others 1988a). PGR's for all partial cuts exceeded the average for resistant trees, being 1.0 or greater at the start of the test and steadily increasing following partial cutting, even in the check stands, which had losses exceeding 30 percent of the trees.

Table 3--Pairwise squared distance of the discriminant function for live and mountain pine beetle killed trees

Treatment	Distance
10-inch diam. limit	0.6155
12-inch diam. limit	0.3513
80 ft^2 BA/a	1.7043
100 ft^2 BA/a	2.1662
120 ft^2 BA/a	1.3393
Check	0.3177

Following partial cutting, stands should still have been susceptible to MPB infestation, based on vigor indices. Average d.b.h. of most stands exceeded the 8 inches specified by Amman and others (1977) and Safranyik and others (1974); grams of wood per square meter of foliage for most trees were still in the highly susceptible category of less than 50 g; and PGR was less than 0.9 in many trees on the Kootenai and Lolo but not on the Shoshone National Forest. However, tree losses were much reduced. Even though trees had not yet responded with greatly increased vigor, the much reduced losses following partial cutting, when compared to uncut check stands, suggest that some factor other than tree vigor is involved. Bartos and Amman (1989) suggest that stand microclimate is responsible, being altered by the partial cutting treatments.

While grams of wood per square meter of foliage was not a good measure of tree susceptibility to MPB infestation in Montana and Wyoming, Mitchell and others (1983b) found this to be a good predictor of lodgepole susceptibility to MPB infestation in stands on the Deschutes National Forest in Oregon. The stands had been thinned 7 to 15 years before the infestation. In that length of time, most stands had exceeded the 100 g of wood per square meter of foliage that separates susceptible from nonsusceptible stands.

Although stand microclimate was considered as a possible cause for differences in beetle behavior among the Oregon stands, it was not studied (Mitchell and others 1983b).

Quantitative and qualitative changes in resins following partial cutting were not explored in the Kootenai, Lolo, and Shoshone stands, as was done in thinned loblolly pine stands in the southern United States in relation to bark beetle attack (Matson and others 1987; Nebeker and Hodges 1983). Nebeker and Hodges (1983) found total monoterpene content did not change with time or treatment. However, greatest terpene increase occurred in trees receiving basal wounds during the thinning operation. This they attributed to stimulation caused by the wounding. Matson and others (1987) observed greater resin production in residual trees in thinnings than in unthinned stands 6 years after treatment. Because of small changes in growth of lodgepole pine in our partial cutting treatments immediately and even 5 years after partial cutting treatment, substantial increase in resin production seems unlikely. This observation, coupled with the slow radial growth and slow change in tree vigor of residual trees, suggests that factors other than tree vigor are governing whether beetles remain in the partial cut stands to infest trees. The most likely factor is change in microclimate as a result of the partial cuts.

MICROCLIMATE OF STANDS AND TREES IN PARTIAL CUT STANDS

Partial cutting lodgepole pine stands causes subtle changes not only in incident radiation, temperature, and light (Reifsnyder and Lull 1965), but also in wind speed. These climatic changes brought about by thinning may have profound effects on MPB activity. The effects of extremely high (Patterson 1930) and low temperatures (Somme 1964; Yuill 1941) on MPB have been reported. However, an optimum zone for temperature and other microclimatic factors has not been defined. Microclimate was measured and compared for thinned and unthinned stands located at 9,400 ft (latitude 41 °N) on the Wasatch National Forest in northeastern Utah (Bartos and Amman 1989).

Microclimatic factors measured in thinned and unthinned stands in northern Utah were: temperature of the outer and inner bark of live trees, air temperature, soil temperature, solar radiation, and wind speed, using either an automatic recording device and thermocouples or an infrared thermometer. The inner bark (phloem) temperature was consistently 2 to 4 °F higher in the thinned than in the unthinned stand. The outer bark (surface) temperature on the south side was 2 to 5.5 °F higher in the thinned than in the unthinned stand (fig. 10). Less difference was observed on the north sides between thinned and unthinned stands. However, temperatures were 5.5 to 7 °F higher on the south than north sides. These differences are consistent with those reported by Powell (1967) in British Columbia. In addition, he found temperatures of infested trees are higher than those of live trees. Powell (1967) reported subcortical temperatures were occasionally 95 °F or higher on south sides. Bartos and Amman (1989) reported an average difference of 4 °F between north and south sides during the hours of 10 a.m. to 2 p.m., with maximum temperature being 22 °F higher in the thinned than unthinned stand. Temperatures on north sides of trees in thinnings would not deter beetle attack. Cooler temperatures on north sides apparently offer more favorable physical environment for attacking MPB. MPB attack

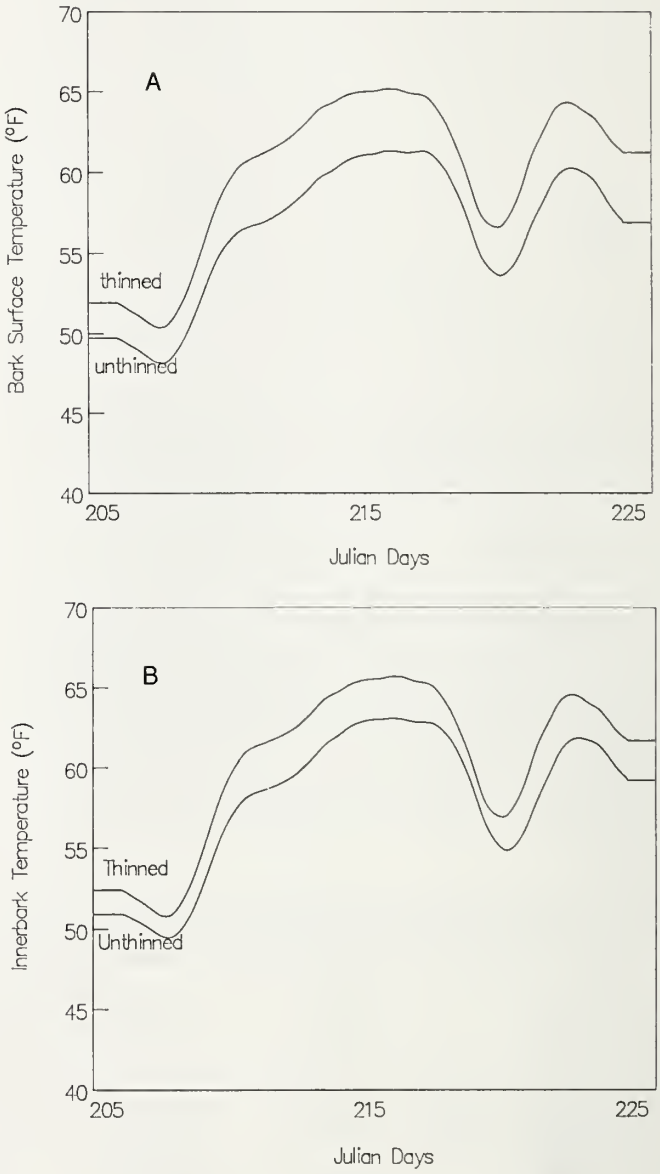

Figure 10--Smoothed curves for a 17-day time period in 1986 contrasting (A) bark surface temperatures and (B) innerbark temperatures on the south side of two lodgepole pine trees between a thinned and unthinned stand (from Bartos and Amman 1989).

densities are higher on north sides (Reid 1963; Shepherd 1965), and when trees are strip attacked, the attacks usually occur on north and east sides (Mitchell and others 1983a).

The effect of temperature could be more subtle than simply creating a direct inhospitable environment for MPB attack. MPB may have evolved behavior to avoid situations where beetle brood are not likely to survive. In thinned stands, high temperatures are not likely to be lethal to any MPB stage (Safranyik 1985). However, where tree temperatures are a few degrees above those of trees in unthinned stands, MPB may proceed too far in their development before winter, thus entering winter in stages that are very susceptible to freezing--for example, the pupal stage--as observed by Reid (1963) and Amman (1973).

The increased wind speed and air turbulence in thinned compared to unthinned stands could disrupt the pheromone communication system of MPB. More sunlight penetrated the canopy in the thinned than unthinned stands (fig. 11), resulting in significantly higher soil temperatures.

Increased soil temperatures, averaging 9 °F higher in the thinned than in the unthinned stand (Bartos and Amman 1989), increase convection currents (Rosenberg and others 1983) and air turbulence that could disrupt pheromone plumes and resultant MPB communication (fig. 12). In addition, wind speed is greater in thinned than unthinned stands (fig. 13), thus possibly further complicating pheromone communications. MPB response to pheromones is more predictable at wind speeds under 3 mph, but a few beetles fly at wind speeds of 4.5 mph. Twice as many males as females fly at wind speeds in excess of 2.4 mph (Gray and others 1972).

In dense stands, sunlight is absorbed by the upper levels of the tree canopy that in turn heat the surrounding air, creating instability in the air within the upper canopy. This creates an inversion in the stem zone that is characterized by more stable air (Chapman 1967; Fares and others 1980). Inversions tend to be more pronounced in dense stands than in sparse ones (Fares and others 1980; Fritschen 1984). Aerosol movement below a dense canopy on a sunny day is trapped beneath the canopy until it flows to a point where the canopy is sparse or has an opening (Fares and others 1980). Solar energy penetrating through canopy openings to the forest floor heats the ground and adjacent air, which becomes buoyant and rises through the canopy opening, carrying the aerosol with it (Fares and others 1980). The aerosol or pheromone plume will be torn apart in the faster, more turbulent air currents that occur above the canopy. Therefore, when MPB infest a tree in a thinned stand, canopy density usually is insufficient to trap the pheromone and move it intact horizontally to attract other beetles. Rather, the pheromone rises through the canopy on convection currents and is dispersed above the canopy. Schmitz and others (in press) concluded that most MPB fly in the bole area beneath the canopy, where the pheromone communication system would be most effective.

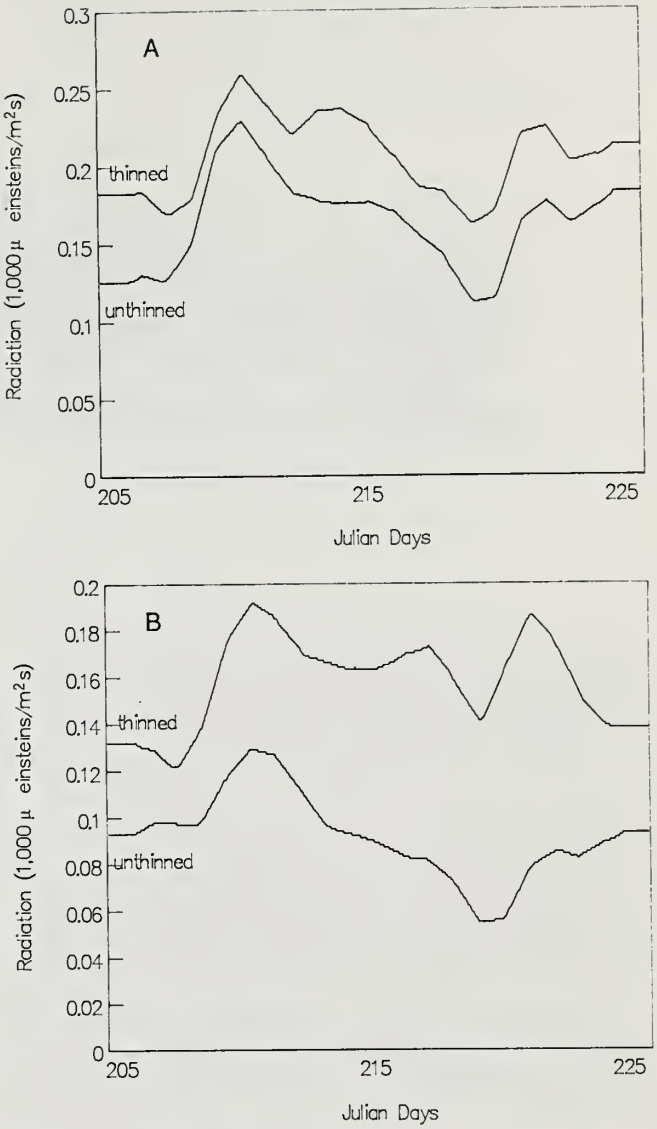

Figure 11--Smoothed curves for a 17-day time period in 1986 contrasting solar radiation (A) at instrument towers and (B) at d.b.h. on trees between thinned and unthinned lodgepole pine stands (from Bartos and Amman 1989).

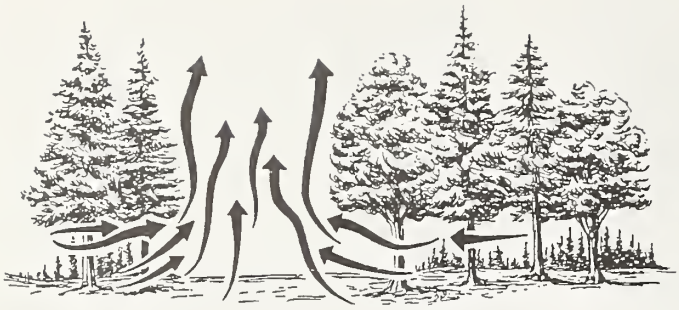

Figure 12--Openings in the canopy tend to act as chimneys when the soil and tree trunks are heated by solar radiation and light winds occur (from Schroeder and Buck 1970).

When MPB do infest a tree in a thinned stand of lodgepole pine, usually only the single tree--and occasionally a nearby tree, when spacing is not maintained--is infested. Geiszler and Gara (1978) emphasized the importance of tree spacing in switching of attacks from a tree under attack to a nearby tree. Trees spaced too far from a tree under attack will not be attacked. The openness of the stand probably causes convection currents created by solar insolation to transport the pheromone plume around infested trees vertically out of the stand rather than horizontally. Thus, the infestation of adjacent trees would be dependent on the degree of thinning. The reduced loss of trees to MPB in all partial cutting treatments in the Kootenai and Lolo studies (McGregor and others 1987) suggests that the density and spacing of natural stands do not have to be changed very much to have an effect on MPB response.

Bartos and Amman (1989) placed three pheromone-baited funnel traps 165 ft apart in both a thinned (67 ft^2 BA/a) and an unthinned stand (137 ft^2 BA/a) that had no currently infested trees. Traps between the two stands were located 330 ft apart. Of the 504 beetles caught, only 5.2 percent were caught in the thinned stands. Either beetles could not find the traps in thinned stands because of disruption of the pheromone plume, or beetles failed to respond because of microclimatic conditions of the stand. Shepherd (1966) showed in laboratory studies that MPB increased attempts to fly as light intensity and temperature increased. Thus, conditions encountered in thinned stands would have been conducive to beetle flight rather than arrestment.

These observations of growth and vigor response of lodgepole pine following partial cutting, MPB response to the partial cut stands, and microclimate changes as a result of partial cutting suggest that microclimate plays a major role in MPB behavior following partial cutting.

Infestation risk of managed lodgepole pine stands probably can be assessed by monitoring stand microclimate, specifically light, which may serve as an integrator of other important microclimatic factors. As tree diameter increases and crown closure begins to occur in partial cut or thinned stands, a favorable microclimate may occur and invite beetle attack, regardless of tree vigor. In addition, thinned stands that contain trees on which branches have not pruned well or that have tall shrub layers may be as subject to beetle infestation as unthinned stands. Additional studies are needed of MPB infestation in thinned and partial cut stands to determine microclimatic thresholds of MPB infestation and the association of thresholds with tree vigor levels, crown lengths, branch pruning, and understory tree and shrub layers.

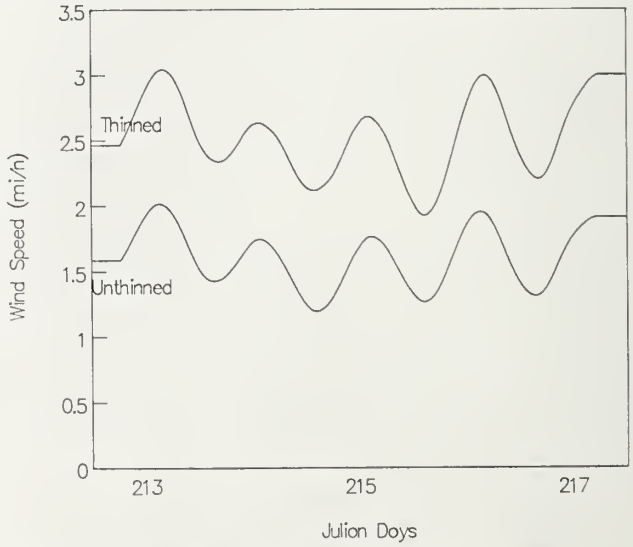

Figure 13--Smoothed curves for a 5-day time period in 1986 contrasting wind speed on instrument towers between a thinned and unthinned lodgepole pine stand (from Bartos and Amman 1989).

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MIXED HOST STRATEGIES FOR MOUNTAIN PINE BEETLE CONTROL IN OREGON

Russel G. Mitchell

ABSTRACT: Lodgepole pine frequently grows in mixture with other tree species. Some of the associates may be other host species of the mountain pine beetle--ponderosa pine, sugar pine, western white pine, whitebark pine--and some may be non-hosts. These mixtures often present special management problems. Specific rules are impossible for all the various combinations that can occur, but some general strategies are possible. Lodgepole pine is a tree that is rather common and is easily cultured on a wide variety of sites. It is also a tree that is very susceptible to mountain pine beetle attack. Accordingly, when lodgepole grows in mixture with other species, a good, general policy is to discriminate against lodgepole pine and manage the other species on the site. On a forest-wide basis, this is a step toward increased diversity. When combined with stocking-level control and management of age classes across the entire forest, the strategy becomes a two-fold management system--one for trees and one for the mountain pine beetle.

INTRODUCTION

The pattern of tree-killing in a mountain pine beetle outbreak is a tragedy sequence--like a Greek play. In the tradition of Greek tragedy, the central figure is a collaborator in its own misfortune; the very characteristic that makes the hero a hero is the same characteristic that ultimately propels him to a disastrous end. Also, once the plot is in motion, nothing--absolutely nothing--will keep it from moving to its fated climax. Here, the "hero" is a forest of mature, over-stocked lodgepole pine--sometimes mixed with other tree species and sometimes in nearly pure stands. The instrument of destruction is the mountain pine beetle.

The mountain pine beetle, unaware of its dramatic role, only does what all living things do--strives to convert as much of the environment as possible into itself and its progeny. A mature, overstocked lodgepole pine forest is ideal for that goal. The scene at the end of the outbreak is classic tragedy. The stage is covered with dead bodies; the lodgepole is dead (at least the larger trees), the beetles are dead, and a few associate tree species--like ponderosa pine, sugar pine, western white pine, and white bark pine--can also perish. Non-host species like larch and true fir, though, may profit from the outbreak. This paper describes some of the interactions of lodgepole pine growing with other tree species and discusses some considerations involved in managing these stands.

THE PROBLEM

In central Oregon, where I work, lodgepole pine often grows extensively in nearly pure forests and is considered climax forest, since little else grows there (Cochran and Berntsen 1973, Cochran 1984). But a large area that has been dominated by ponderosa pine will also support lodgepole pine. Accordingly, where and when conditions are right, lodgepole often invades the ponderosa pine stands. This pattern has increased in the last 75 years because of the effectiveness of the program to control wildfires. Before fire control, the fire frequency in ponderosa pine stands in central Oregon was 8 to 15 years (Bork 1984) and lodgepole pine, which is sensitive to even low-intensity fires, rarely survived long enough to produce seed.

Second-growth ponderosa pine is a well-documented host of the mountain pine beetle, mostly in over-stocked, poor-site (poorer than site III) stands (Sartwell and Stevens 1975). But lodgepole pine is relatively more susceptible. To date, the only significant beetle-kill in ponderosa pine in central Oregon has been where it is closely associated with lodgepole pine--most commonly where a concentration of beetles attracted to an individual lodgepole pine has been so great that the lodgepole pine could not accommodate all the beetles and the surplus killed a few adjacent ponderosa pines.

A more serious problem with ponderosa pine develops as outbreaks die out in local areas. When beetle populations are extremely high and the reservoir of preferred lodgepole pine is about exhausted, any associated ponderosa pine are in serious jeopardy of being attacked by a large number of beetles searching desperately for hosts. Most of the trees attacked are pole-sized ponderosa pine, but a few very large ponderosa pine may also be killed. The good news in this pattern (besides the fact that, usually, few large trees are killed) is that attacks on ponderosa pine signal the end of the outbreak in the area, usually within 2 years--a lot of beetles die in unsuccessful attacks and beetle survival is poor even in those trees that are killed. This pattern should not

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be confused with over-stocked stands of pure, pole-sized ponderosa pine; such stands can generate outbreaks independently, particularly on poor sites.

Sugar pine and western white pine are part of a more complicated mixture. Both species are associated with ponderosa pine as well as lodgepole pine; true firs may also be found in the white-pine mixture. The difficulty in managing these stands is that beetles seem to attack both sugar and white pine almost as readily as lodgepole pine. Attacks have been observed on some very large sugar pine and white pine, and beetle survival--because of the very thick phloem in these trees (Amman 1969)--appears to have been quite good.

An uncommon association, occurring only at the top of a few mountains (above 7,000 feet in central Oregon), is lodgepole pine and whitebark pine. In these areas, the trees are often fairly large in diameter but usually quite stunted; most trees are less than 20 feet tall. Bark and phloem on these trees are typically thin and beetle survival is usually so low that populations probably could not persist if beetles were not being supplied from the infested forest below.

When mixed with larch, true fir, and spruce, lodgepole pine can dominate the forest type or it can be subordinate in the association. Growth rates are often good in this association, and some of the largest lodgepole pine are found on these sites. An interesting feature of beetle attack in these stands is that trees are found and killed by the mountain pine beetle in the same pattern followed in stands where lodgepole grows closer together; trees over 12 inches DBH are nearly all killed, and the probability of attack drops off as tree diameter declines. Often the beetle-kill in these stands proves beneficial. Many stands dominated by larch apparently started out as a mixture of larch and lodgepole pine; the beetle, in this case, is a useful thinning agent.

MANAGEMENT STRATEGIES

Decisions in mixed species management must factor in several considerations, principally beetle biology, tree biology, and economics. Then, evaluation shifts to such questions as impacts on wildlife, grazing, and esthetics. Finally, the decision becomes a local one when the need for diversity enters into the process. Considerations range from intervention with chain saws to benign neglect--and many choices in between. Some of the features to be considered when a given blend of tree species are to be managed for tree growth and beetle management are outlined below.

Lodgepole pine/ponderosa pine

Some factors that enter into the management decision for the lodgepole/ponderosa pine type are:

- Lodgepole pine is more susceptible to attack by the mountain pine beetle than is ponderosa pine when the two species are growing together.
- Ponderosa pine is most susceptible on the poorest sites; it is not very susceptible on sites better than site IV. Lodgepole pine, on the other hand, seems to be about equally susceptible across all sites, once the outbreak is in motion.
- In outbreak situations, thinning to stocking levels of 60 to 80 square feet per acre provides beetle protection for both ponderosa and lodgepole pine, but it works better in ponderosa pine.
- When both species are managed at the same stocking levels on the same site, lodgepole pine will outgrow ponderosa pine for about 50 years (Dahms 1983). Also, lodgepole will produce a tree with less taper, less bark, smaller branches, and less sapwood.
- For rotations longer than about 80 years, ponderosa pine will outgrow lodgepole pine in volume and will produce larger trees that are more valuable (on a board foot basis) than small trees (Barrett 1979).
- If both species are to be managed on the same site, ponderosa pine must be planted; relying on natural regeneration through shelterwood, seedtree, or selection systems would mean that lodgepole pine would eventually dominate the site because of its superior seeding characteristics. Site treatments to correct the inbalance, such as prescribed fire, may be possible but would likely require heroic efforts.

After contemplating these points, the forester needs to ask whether more lodgepole pine is wanted. In central Oregon, we already have more then 500,000 acres of topo-edaphic climax lodgepole pine--stands where we can grow nothing else but lodgepole pine. Accordingly, a choice to discriminate against lodgepole pine, in stands where it is mixed with ponderosa pine, is a choice for increased diversity because lodgepole eventually dominates these sites if left alone. It is also a choice for more beetle resistance under appropriate stocking control and for rotations longer than 80 years. Finally, encouraging ponderosa pine makes economic sense. According to a simulation analysis by Znerold (1988), which factored in growth response and reduced beetle susceptibly, stocking control in second-growth ponderosa pine will produce a benefit/cost ratio of about 3 to 1. In the current economic climate, achieving that kind of ratio with lodgepole pine is unlikely.

Lodgepole pine/sugar pine/ponderosa pine

Ponderosa pine is less susceptible to mountain pine beetle than either sugar pine or lodgepole pine. Also, sugar pine seems to be slightly less suceptible to beetle attack than does lodgepole pine. Accordingly, the management approach to this type is similar to the mixed forest just mentioned--that is, encourage ponderosa pine and sugar pine. The question then becomes how much sugar pine to save. Because of the risk with sugar pine, the safest approach would be to strive for minimum acceptible stocking with ponderosa pine, then add sugar pine. Sugar pine is a fine tree from several perspectives. It offers diversity, and susceptibility to beetle attack would likely be lowered if the trees were well spaced and lodgepole pine eliminated from the stand.

Lodgepole/western white pine/true fir

The association of lodgepole/western pine/true fir also has some problems similar to those in the ponderosa/lodgepole type. An important difference, though, is that this mixture occurs at higher elevations (above 6,000 feet in central Oregon) and usually contains true firs as well as a few fast-growing ponderosa pine. Again, the philosophy is to strive for diversity along with beetle resistance. Diversity with resistance is accomplished by maintaining white pine, ponderosa pine, and true fir, but with a serious attempt to remove all lodgepole from the stand. If larch is present, it would be used too. The response of western white pine within this mixture is unknown. White pine is rather susceptible to the mountain pine beetle, and the risk of managing a stand containing western white pine(aside from blister rust) is that the tree will attract beetles into the stand and become a threat to the residual ponderosa pine. The risk may be worth taking, however; western white pine is a magnificent tree in just about every respect. Further, the ponderosa pine on sites where true fir grows is usually less susceptible to beetle attack than when it grows at lower elevations.

Lodgepole/whitebark pine

Management within lodgepole/whitebark pine stands is probably impractical just about everywhere. The trees are too stunted to have commercial value, and they already grow so far apart that thinning would be meaningless. Because of poor beetle survival, the populations in these trees appear to be non-sustaining. Thus, the best chance to improve the beetle situation in these stands would be to manage the lower elevation stands that seem to be supplying the beetles.

Lodgepole pine/larch/true fir/spruce

Very often the best management policy in lodgepole/larch/true fir/spruce stands, from the standpoint of the mountain beetle, is benign neglect. If the amount of lodgepole in the stand is less than 50%, letting the beetle kill those trees for the thinning effect is usually beneficial. Keeping lodgepole in the mixture and managing at stocking levels that would avoid significant beetle problems is also possible. The problem with this strategy is that the stocking levels needed to avoid the beetle in lodgepole are so low that the strategy does not even come close to capturing the capacity of the site to produce wood if it were managed for one or more of the non-host species. Accordingly, the decision is usually to eliminate the lodgepole pine and manage for larch, true fir, and spruce.

DISCUSSION

The key management pattern described above is obvious; discriminate against lodgepole pine but also strive for diversity within stands and across the forest. That strategy is closely followed by stocking control. The focus on discrimination stems from the fact that lodgepole pine is the most susceptible of the native western pines. The other reason for discriminating is that we have so much lodgepole pine and more can easily be grown--if we want it. Lodgepole pine usually will produce more progeny than any of its neighbors and do it year after year; its rapid juvenile growth means it will compete during the establishment period with most other plants; and its huge ecological amplitude lets it grow on a very wide range of sites, including some where nothing else will grow.

But lodgepole pine may be wanted on some of those sites; if so, it can be grown by managing the stocking levels. In the worst-case situation (a small island of thinned lodgepole in a sea of unmanaged lodgepole), the mortality rate even of large trees can be cut in half during an outbreak. For trees in the 6- to 9-inch DBH classes, survival is improved 4 to 5 times by thinning. The problem as noted above, though, is that if we manage for lodgepole in the mixture, the spacing is so wide that we are failing to capture a significant part of the sites productive capacity. Also, we do not know how long a thinning in lodgepole pine will endure. A biological limit must certainly control how long we can grow lodgepole pine, and the mountain pine beetle will probably dictate that length. But that limit is certainly longer in a stand where stocking level is managed--maybe a lot longer.

The important thing to remember about managing beetle-susceptible forests is that the mountain pine beetle is a FOREST pest. "Forest" is emphasized because we cannot manage 40 acres here and 40 acres there and expect much protection from the mountain pine beetle. Beetles build up in unmanaged stands and can fly a long way. And when beetle populations are large, they expand their food supply; trees that would normally resist

beetle attack at low or moderate populations are often overwhelmed at high populations. We must manage nearly all our forests, pure stands of lodgepole pine as well as stands of mixed species. When we do that, we are managing beetle populations as well as the forest. Then, with reduced opportunity for beetle populations to grow, we can introduce a little flexibility in our management style--perhaps take a few chances and grow an overstocked stand here and there; maybe increase the mix of sugar pine or western white pine; or let something go for a few years while we take care of some other high-priority problem.

The mountain pine beetle is a real pain. If we did not have it, we could probably lengthen our rotations, grow some rather sizable lodgepole pine, and improve the volume increment on many of our sites where we now have pine. But consider another possibility: perhaps the mountain pine beetle is really not a curse from the gods but a gift, sent to give us some direction on how to manage a whole forest for growth, diversity, and the best possible mosaic of age distribution and species composition. The mountain pine beetle is, in fact, another one of those things that makes forestry anything but a schedule of routine prescriptions; it is this kind of a problem that adds excitement to our professional lives and makes it fun to go to work in the morning. So the tragedy may not be that we have the mountain pine beetle, but rather that through poor focus on management needs, we have let the beetle get out of control.

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PREVENTIVE STRATEGIES FOR LODGEPOLE PINE/MOUNTAIN PINE BEETLE PROBLEMS: OPPORTUNITIES WITH IMMATURE STANDS

Dennis M. Cole

ABSTRACT: Culture of immature lodgepole pine stands is seen as a critical part of long-term prevention strategies for reducing future resource losses from the mountain pine beetle. This paper describes applicable practices for immature stands and discusses their strategic role in attaining a forest-wide mosaic of stands varying in age, size, composition, and structure. A diverse forest mosaic is considered necessary for avoiding severe mountain pine beetle outbreaks in commercial forests.

INTRODUCTION

Strategies to minimize losses to the mountain pine beetle (Dendroctonus ponderosae Hopk.) include a variety of practices that differ in intent and effectiveness. Some seek to reduce losses by prevention, some by recovery and utilization of otherwise lost trees, and others by amelioration of effects. A diagram classifying practices, intents, tactics, and strategies for controlling losses to the mountain pine beetle (MPB) in lodgepole pine (Pinus contorta var. latifolia) forests was developed earlier (Cole 1978). The practices discussed in this paper include those prevention tactics identified in that classification (fig. 1).

Although this topic associates strategies with stands, it is really the forest, over time, that we are concerned with in developing prevention strategies for reducing losses to the mountain pine beetle. This distinction focuses the generalized goal of reducing losses to the specific objective that will accomplish it--namely the management of endemic mountain pine beetle populations to prevent their increase beyond endemic levels. This means that strategies for immature stands must be developed and executed as an integral part of ongoing, long-term, forest-wide programs for managing the age, structure, composition, and vigor of stands--and their juxtaposition across the landscape--to keep mountain pine beetle populations endemic. Such programs will include (along with strategies for immature stands) silvicultural strategies for mature/overmature stands as discussed earlier in this symposium, and utilization and chemical intervention strategies to be discussed in following papers. The overview and field trip discussions of silvicultural and resource management strategies for addressing the mountain pine beetle problem on the Swan Lake Ranger District of the Flathead National Forest will illustrate and provide context for many of the points discussed in this and the other papers.

The objective of this paper is to review appropriate silvicultural practices and strategies for minimizing future resource losses from the mountain pine beetle, in relation to immature stands. The stand--and often the individual tree or tree type--is the focal point in applying most of the cultural practices discussed; but to emphasize the critical forest-wide perspective needed in this issue, the focus here will be on opportunities for increasing future forest diversity through management of immature stands. Such diversity benefits nearly every resource of concern and is particularly important in minimizing forest losses from insects and disease.

APPLICABLE STAND-TENDING PRACTICES

Cultural practices for immature lodgepole pine stands have been identified for years (Smithers 1961; Tackle 1961). More recently, their role in the battle against the mountain pine beetle has been described (Cole 1978; Cole and McGregor 1985; Safranyik 1982; Safranyik and others 1974). Several practices for immature stands can contribute to the avoidance of future outbreaks of the mountain pine beetle. They are:

- Improvement and Sanitation Cuts
- Manipulation of Stand Density, Composition, and Structure
- Early Stand Replacement

Although not large in number, the flexibility in scale, scope, and timing of these operations provides the manager with an effective set of tools for affecting future forest diversity.

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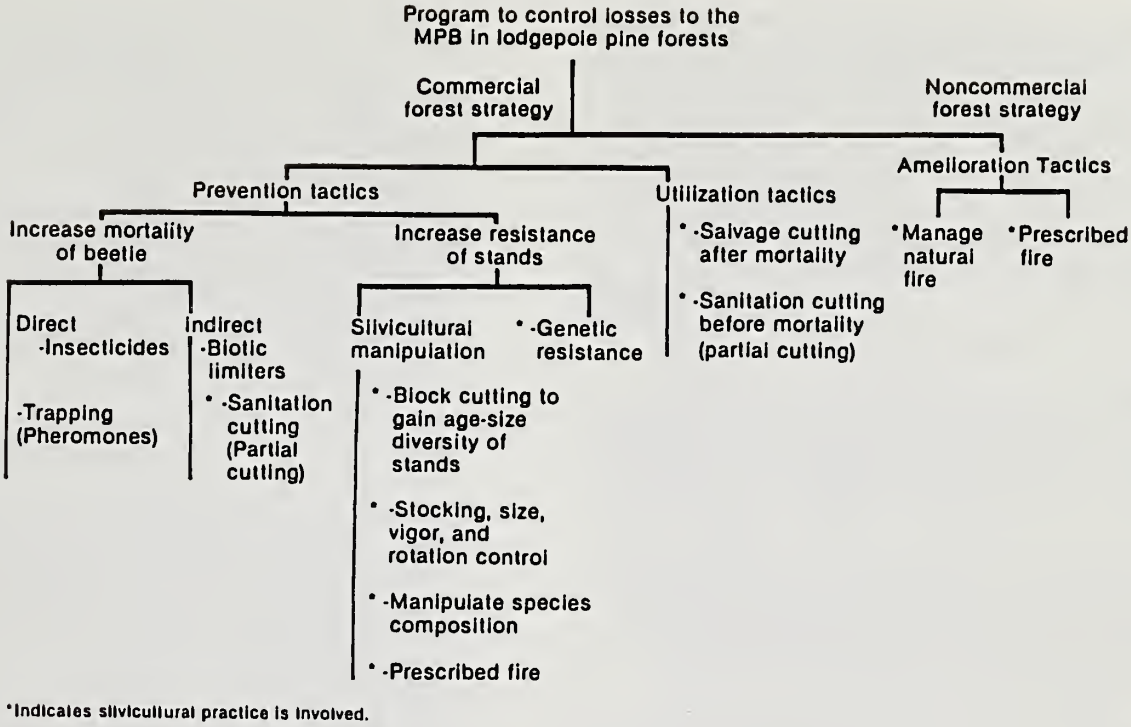

Figure 1--Place of immature-stand culture in strategies for controlling losses from the mountain pine beetle (from Cole 1978).

Improvement and Sanitation Cuts

Improved health of even-aged and uneven-aged lodgepole pine stands can be attained by stand tending keyed to detecting and removing diseased, damaged, or otherwise unhealthy trees. Many disease and damage effects occur in immature lodgepole pine stands (Krebill 1975; Lotan and Perry 1983); however, only lodgepole pine dwarfmistletoe (Arceuthobium americanum), wind, and snow warrant special mention. Stem rusts and root diseases can be locally debilitating in some lodgepole pine stands and predispose affected individual trees to bark beetle attack (Christiansen and others 1987), but effective control measures are not yet known (van der Kamp and Hawksworth 1985).

Dwarfmistletoe infection can predispose trees and stands to bark beetle attack by reducing tree and stand vigor. Ideally, dwarfmistletoe should be excluded from lodgepole pine stands in the regeneration phase of management. Where regenerated stands less than 20 years old occur with scattered infected residual trees from the previous stand, the infected residuals should be killed. In older infected stands, degree of infection should be determined (Hawksworth 1977), and thinning or partial cutting considered, for those stands not heavily infested. This will reduce infection levels and slow the decline in growth and vigor of the stand (van der Kamp and Hawksworth 1985).

Heavily infested stands approaching maturity, that have infected trees exceeding 8 inches d.b.h., should be partially cut to remove these beetle-attractive trees if sufficient growing stock remains for a reasonable yield at rotation. If growing stock would be insufficient, early replacement of the stand through regeneration harvest should be considered.

Wind and snow damage is common in immature lodgepole pine stands following thinnings or partial cuts, when the stand has been opened too much or extreme wind or snow has occurred. Wind damage can be minimized by adjusting thinning intensity to the exposure situation of the stand (Alexander and others 1983). Thinning adjacent to clearcuts where the prevailing wind angle approaches 90° should probably not exceed 40 percent of the basal area in a single entry (Schmidt and Barger 1987). Trees weakened by snow or wind damage are attractive to endemic mountain pine beetle and secondary bark beetles, and help mountain pine beetle populations survive at low levels and increase from those levels. Managers should pay close attention to heavily thinned stands, particularly those thinned from below, following heavy winds or snowfall. Obviously damaged trees should be removed promptly to deny them as breeding grounds for bark beetles, and to improve the general health and condition of the stand. Stands also can suffer unseen wind damage.

Trees that resisted wind-falling can suffer root damage from swaying and become attractive to bark beetles as a consequence (Christiansen and others 1987). Although such trees are difficult to detect until after-the-fact, bark beetles can detect them and focus attacks on them. Therefore, such stands, particularly those with size classes of lodgepole pine in or near them that are favorable for increasing mountain pine beetle populations, should be watched closely for several years following severe windstorms. Any trees colonized by bark beetles should be destroyed or removed from the stand before dispersal of broods from them.

In general, a forest-wide policy and program for stand improvement and sanitation of immature lodgepole pine stands will accomplish long-term benefits by reducing the number and severity of mountain pine beetle outbreaks. Mixed lodgepole pine stands, particularly those having a good representation of other species in the overstory, provide even more opportunities than pure stands for improvement cuts, for in them species discrimination against lodgepole pine can contribute to long-term reduction in mountain pine beetle hazard.

Manipulation of Stand Density, Composition, and Structure

The character and condition of immature stands can be greatly influenced by intermediate cuttings. Thinning appears to have the greatest potential for increasing or maintaining the vigor and growth of lodgepole pine trees and stands and thus contributing greatly to long-term prevention strategies for the mountain pine beetle (Cole and McGregor 1988). Both stocking control and intermediate thinnings are beneficial in this respect. Low thinning is the preferred thinning method for immature lodgepole pine, but the timing and spacing of thinnings to have a maximum effect on discouraging mountain pine beetle outbreaks are not yet clear. Early results from research studies (Mitchell and others 1983; Pitman and others 1982) and observations of operational thinnings in mountain pine beetle outbreak areas indicate that recently thinned older stands are passed over in the early stages of outbreaks, but might suffer some mortality in later stages when favorable host trees are depleted from surrounding unmanaged stands. Although larger trees in thinned areas still are vulnerable to epidemic mountain pine beetle populations, this does not disqualify thinning as a prevention practice.

Rather, the fact that even in outbreak situations thinned stands usually suffer a lower percentage of mortality of susceptible-sized trees, suggests that had thinning and other stand-tending practices been the norm rather than the exception the mountain pine beetle outbreaks might not have occurred (Cole 1978).

There is still debate as to whether the apparent benefit of thinning in reducing mortality from the mountain pine beetle is due to its effect on tree vigor or on the micro-environment influencing the beetle--or a combination of the two. Regardless of the exact and fundamental entomological explanation, thinning can be considered a valuable practice in long-term prevention silviculture for the mountain pine beetle problem. However, because too small a proportion of our lodgepole pine forests are likely to be thinned soon enough to fully succeed in prevention it is important that the fundamental effect of thinning on the mountain pine beetle be determined. Without this information, we do not know specifically how and when to thin or rethin stands approaching the mature stage. With this lack of knowledge we may delay mountain pine beetle outbreak by thinning, but set the stand up for even greater losses if the cause and duration of the thinning benefit are not thoroughly understood. With these uncertainties, what recommendations on type, intensity, and timing of thinnings, can be given for immature stands?

I believe the safest strategy at this time for pure immature lodgepole pine stands is to plan and execute an expanding program of thinning to accomplish stocking levels and growth rates that culminate and allow stand rotation at about 80 years of age (Cole 1975, 1978). The age, structure, and vigor of stands managed under this strategy are not considered to be highly susceptible to the mountain pine beetle (Amman 1978). When implemented on a forest-wide scale--with other factors (such as varied size and juxtaposition of stands) a richer forest mosaic can be created and hazard levels should be greatly reduced.

Another way of gaining diversity in the forest mosaic is through intermediate or repeated thinnings in older but still immature lodgepole pine stands. Culminated yields cannot be expected from such treatments at rotations of less than 120-140 years unless thinning intervals are 40 years or more (Cole and Edminster 1985). But it is questionable if such long thinning intervals can maintain tree and stand vigor at high enough levels to discourage mountain pine beetle outbreaks. Therefore, if low hazard is to be maintained in extended rotations, repeated light thinnings at 10-20 year intervals will probably be necessary, and less-than-culminated yields accepted at eventual rotation.

In mixed species stands, where there is a manageable alternative to lodgepole pine, diversity can be accomplished by manipulating species composition and stand structure in the course of thinning immature stands. Discrimination against lodgepole pine in these situations also allows for longer rotations than is safe with lodgepole pine, thus providing additional levels of an important factor for varying the forest mosaic.

In addition to reducing potential for future losses to the MPB, there are other opportunities and amenities that can result from thinning. Thinning patterns to enhance or achieve greater forest diversity can benefit other resource values and thus in many cases be largely justified by those objectives alone. As an example, thinning prescriptions can be designed to affect species composition and canopy development and modify hiding, thermal, and forage cover ratios important to wildlife. Water quality and yield are also important values justifying the creation of thinned stand patterns in high-elevation lodgepole pine forests.

Early Stand Replacement

Overall forest diversity can also be promoted by another practice applicable to immature stands--early stand replacement. Overstocked stands, or portions of them, can be clearcut for round-wood products and firewood or simply trampled and burned in place. Varying the timing and spatial arrangement of these treatments, in conjunction with species choices in the regeneration of the site, will help in attaining greater age class, stand size, and species diversity in our lodgepole pine forests. In the following section, the importance of planning in increasing immature stand and overall forest diversity is discussed.

PLANNING FOR INCREASED FOREST DIVERSITY

The scope and intensity of recent mountain pine beetle outbreaks show the difficulty of trying to prevent or limit the effects of outbreaks when there is a preponderance of mature and overmature stands--and when only a small proportion of the stands have benefitted from stand culture. Failure to use all opportunities to achieve an improved mosaic of age classes, species composition, and stand sizes of lodgepole pine stands in the next several decades will almost surely result in another cycle of serious losses to the mountain pine beetle. Otherwise-sound silvicultural prescriptions, determined on a stand-by-stand basis, will not greatly improve the situation unless they contribute to greater forest diversity. To accomplish that they must be determined in a much wider context than has usually been the case.

The good news is that several factors have evolved to the point where they facilitate and justify prevention prescriptions and programs that until recently were not feasible. Among these are: (1) the improvement in multiresource data bases, (2) the demand for a better balance in resource protection and productivities, (3) the widening public recognition that costs for prevention of resource losses are good investments, and (4) recent advances in computer-aided technologies. The data base and computer technology advances are especially significant: they provide breakthroughs in mapping land, forest cover, habitat, and stand types, and in analyzing phenomena planned or occurring therein. Known as geographical information systems (GIS), the more advanced of these systems are able to integrate a variety of map projection data formats with associated resource data bases to produce a huge array of analyst-chosen resource maps. Among the capabilities of these systems are several that have great value for planning and managing our forests for prevention of mountain pine beetle outbreaks:

- *The ability to identify locations meeting analyst-specified criteria.* Maps showing the scope and spatial distribution of all lodgepole pine stands--by land type, habitat type, successional role, and stand type--in a National Forest or region, would be an example of this.

- *The ability to assess impacts.* Effects wrought by the mountain pine beetle or programs designed to prevent mountain pine beetle effects can be evaluated visually and statistically. Information from a variety of sources--such as biological relationships, rules of thumb, expert opinion, management policy--can be combined in one or more steps to produce the desired impact estimates. The use of GIS to assess mountain pine beetle impacts on the Butte Ranger District of the Deerlodge National Forest, as described earlier in this symposium, demonstrates that this technology is already being brought to bear on the mountain pine beetle problem in the area of resource impacts.

- *The ability to preview and assess trade-off options.* Responding to mountain pine beetle epidemics or taking long-range steps to prevent them involves the balancing of impacts on different resource values. By providing spatial representations of different trade-off decisions for various future time periods, an optimum strategy for the criteria used can be identified.

- *The ability to integrate the above capabilities.* Advanced systems integrate their major features, thus solution values from each routine are available to the other routines to allow updating of management alternatives at chosen future time periods.

CONCLUSIONS

Taken together with our considerable ecological knowledge of host and pest, the exciting new capabilities in spatial analysis, and the increased public desire for reducing resource losses, it appears safe to say that we are on the threshold of a new era of forest-wide resource protection and management through silviculture. A good start in attaining desirable forest diversity has already occurred

through the cutting and regeneration patterns of the past 40 years--and now through a variety of intermediate and harvest cutting practices precipitated by recent MPB outbreaks, or the threat of them. Increased silvicultural management of immature stands can play a central role in reducing future resource losses caused by the mountain pine beetle.

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UTILIZATION OPPORTUNITIES FOR REDUCING MOUNTAIN PINE BEETLE DAMAGE IN LODGEPOLE PINE

Carl E. Fiedler

ABSTRACT: The "window of opportunity" for utilizing dead lodgepole pine for most high-value products is less than five years. Consequently, management focus during beetle epidemics is on salvaging dead and threatened trees. Thinning to increase tree vigor and regeneration cutting to develop species and age-class diversity are silvicultural strategies for reducing losses in the future. Broad-scale application of these strategies is dependent upon utilization opportunities, especially for subsawtimber-size trees. Ironically, a proposed multi-product manufacturing facility that would utilize small trees for high-value products is currently on hold. Social and administrative factors hinder assurance of a dependable supply of raw material for the plant, despite an excess of small timber in the procurement area.

INTRODUCTION

Not so long ago, lodgepole pine (Pinus contorta Dougl. ex Loud.) was considered little more than a weed that got in the way of real trees. As recently as the 1960's, Hutchison (1964) noted that "the popular impression of lodgepole pine is of a skinny tree growing out on the edge of nowhere." But times change, and several situations have developed to increase interest in utilization of lodgepole pine. First, a dwindling old-growth timber supply in the West has gradually shifted emphasis toward increased utilization of smaller diameter material such as lodgepole pine. Second, and probably more important, the mountain pine beetle (Dendroctonus ponderosae Hopkins) epidemic that is devastating large areas of lodgepole pine in the northwestern United States and western Canada has heightened interest in utilization opportunities for dead or threatened lodgepole. In addition, because it is lightweight, has small, tight knots and desirable drying characteristics, lodgepole pine has come to be recognized as a quality lumber species. The purpose of this report, then, is to present current opportunities to use lodgepole pine (live and dead) for solid products, reconstituted products, or energy.

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CONSTRAINTS ON UTILIZATION

Timely utilization of beetle-killed or threatened lodgepole pine is complicated by several factors. First, large volumes of material suddenly become available for utilization, with little advance notice. Consequently, timber harvest schedules must be altered and traditional planning horizons shortened. This situation has also forced land managers and the forest products industry to look for new utilization opportunities. From the standpoint of utilization for most products, beetle-infested stands represent a classic "use it or lose it" proposition.

Beetle epidemics leave public land managers in an especially untenable position. On the one hand, managers must contend with large volumes of dead or threatened timber; yet they have only a short "window of opportunity" to utilize this material for high-value products. They also are faced with various nontimber resource constraints and limited utilization opportunities. Furthermore, the more organizational resources that are directed at salvaging beetle-killed material, the less are available for other stand management needs.

Mountain pine beetle epidemics also leave the forest products industry in a difficult position. The sheer volume of lodgepole pine killed by beetle attacks often exceeds both the capability of the industry to recover this material and the capacity of mills in the area to utilize it for high-value products. While the temporary glut of raw material caused by beetle epidemics may benefit the timber industry in the short run; it has serious timber supply implications in the long run, since most of the lodgepole pine type is in public ownership (Barger and Fiedler 1982). Accelerated harvest in certain locations now may limit raw material availability in the future because of hydrologic constraints and wildlife concerns.

Mountain pine beetle epidemics affect long-term timber supply in another more insidious way. Scattered, standing-dead trees that have died from such endemic causes as suppression, lightning, or root rot are usually not included in forest inventories, and therefore are not included in allowable cut calculations. To the extent that these trees are salvaged in green timber harvest operations, they are excess supply. Conversely, the many thousands of trees killed in stand-level mortality events (e.g. mountain pine beetle epidemics) have been counted in green timber forest inventories, and therefore included in allowable cut calculations. To the

extent that this mortality is not salvaged and utilized, allowable cut allocations will have to be reduced in the future. Some organizations (e.g., Montana Department of State Lands, USFS Northern Region) have attenuated the impact of this potentially severe problem by adjusting yield table volumes downward based on projected mortality to the mountain pine beetle.

UTILIZATION-MANAGEMENT RELATIONSHIPS

A variety of management strategies exist to reduce mountain pine beetle losses in both immature and mature stands. Application of most silvicultural strategies, however, depends on markets for material removed in harvest treatments. Without profitable utilization opportunities, the manager has little flexibility to reduce susceptibility in immature stands, to recover dead or threatened material in mature stands, or to control the composition and density of regeneration following stand replacement.

Management strategies that involve timber harvest to reduce losses can either take the form of thinning treatments, regeneration cuttings, or sanitation-salvage operations. Thinning treatments are usually applied to immature sapling- and pole-size stands to increase leave-tree vigor and decrease susceptibility to mountain pine beetle attack. This appears to be an especially effective strategy in younger stands for reducing long-term losses to the beetle. Trees removed in thinning are usually smaller than the mean stand diameter, so primary utilization opportunities, if any, are for small roundwood products or reconstituted products. With limited utilization opportunities for small trees, however, managers have been unable to apply intermediate treatments as needed. Preventive thinning treatments may have limited applicability in areas where much of the lodgepole pine is mature and of sawlog size.

Application of regeneration cutting to develop a mosaic of species and age classes is another form of preventive treatment. Again, lack of demand for the subsawtimber component of harvested stands often means that smaller trees must be treated as a residue, at added cost.

Once an epidemic is underway, the primary means of reducing losses in middle-aged and mature stands is through recovery, rather than prevention. Recovery can be accomplished through sanitation-salvage cutting in stands where the infestation is not yet severe, and by regeneration cutting where it is. In either case, dead trees and those in imminent danger of attack are harvested while they still have value for products. Dead trees removed in salvage operations are usually larger than the mean stand diameter, so primary utilization opportunities include houselogs, studs, plywood, and reconstituted products.

Losses to the mountain pine beetle could theoretically be eliminated if all dead trees were utilized while they still had wood quality and appearance characteristics appropriate for their highest potential end use. In reality, managers are unable to keep up with the large volumes and broadly dispersed nature of mortality in beetle epidemics. Under these conditions, raw material supply is a transitory rather than a reasonably stable inventory quantity. Recovery must be rapid if dead trees are to be used for products with strict wood quality specifications, but can be extended somewhat if trees are used for most reconstituted products (with the exception of waferboard and oriented-strand board) or energy purposes.

Unfortunately, the value of dead lodgepole pine for products is generally inversely proportional to the "window of opportunity" for utilization. For example, dead lodgepole pine are usable for such high-value products as veneer for only 1 year (Snellgrove and Ernst 1983), and utility poles for 0 (Brown 1988) to 5 years (Tegethoff and others 1977). Dead trees can be used for moderate-value products such as studs for up to 4 years (Dobie and Wright 1978; Sanders 1988). Dead trees are usable in the manufacture of oriented-strand board for less than 1 year without wetting, and up to 4 years with specialized provisions for wetting (Koch 1988). Utilization for low-value uses such as pulp extends at least 7 years (Lowery and others 1977), and for energy at least 15 years.

UTILIZATION OPPORTUNITIES

Essentially all of the wood fiber comprising either immature or mature lodgepole pine stands is potentially usable. Its underutilization is a result of one or more of the following factors: limited demand, limited road access, management constraints, high logging costs, low product value, distance to primary markets, and limited rail service (Fiedler and others 1988). The value use of wood, defined by Keegan and Jackson (1986) as the amount a user is willing to pay for delivered wood over the long-term, strongly influences utilization opportunity. For example, delivered value use (table 1) can be compared to delivered cost (table 2) at the processing facility to estimate utilization potential for various stem size-product/use combinations. The "value use" versus "cost" comparisons provide only relative utilization potential. Tree size and wood quality characteristics obviously limit potential roundwood and sawn product uses (e.g., 4-inch diameter trees cannot be used for studs, and 16-inch diameter trees cannot be used for fence rails). In addition, while value use for such products as grape stakes, posts, and fence rails is high, demand is limited relative to the huge supply of small-diameter material. Koch (1987) estimated that over one third of the total volume of lodgepole pine is in trees less than 7 inches in diameter. Because small trees are so costly to harvest (table 2), high-value uses other than those mentioned above will have to be developed if significant volumes of subsawtimber size trees are to be utilized.

Consumer tastes also have a significant effect on utilization, especially for specialty products. Utilization of lodgepole pine for such tradi-

Table 1--Estimated delivered value use of wood fiber in the Inland Empire for solid products, reconstituted products, or energy (1984 dollars).[1]

Product or use	Value
	[2]($/cu. ft.)
Solid products	
Houselogs	.93-1.30
Studs	.60- .90
Posts and poles	.50- .80
Reconstituted products	
Particleboard	.15- .42
Fiberboard	.30- .80
Waferboard	.40- .80
Pulp and paper	.40- .80
Energy	
Fuel oil	.00- .70
Natural gas	.00- .65
Coal	.25- .35

[1]Adapted from Keegan (1987).
[2]One cubic foot of wood equals 25 lbs. (ovendry basis).

tional products as studs and reconstituted products is fairly predictable over the long term, with fluctuations in demand due mainly to national economic cycles. Utilization for specialty products (e.g., houselogs, blue-stain paneling) is also affected by economic "times," but in addition is subject to changing and unpredictable consumer tastes. For example, the popularity of log homes has increased over the last decade, and with it the demand for houselogs. Both the log home market and the demand for houselogs remain strong (Montana Extension Service 1988). Conversely, decorative paneling manufactured from beetle-killed trees and marketed as "blue-stain pine" was a popular item in the late 1970's and early 1980's. However, both raw material supply and consumer demand have since declined in most areas where this product was manufactured and marketed (Ostermann 1988). Despite this short-lived popularity, blue-stain paneling provides a good example of the potential of innovative marketing to increase utilization levels over those for traditional products or uses alone.

RECENT DEVELOPMENTS

The earlier discussion assesses the potential for utilizing either the green trees removed from immature stands or the dead or threatened trees removed from mature infested stands for the manufacture of traditional products. A recently developed proposal for an integrated, multi-product manufacturing facility in northwestern Montana would provide for large-scale utilization (155,000 tons annually, ovendry basis) of lodgepole pine for both traditional and nontraditional products (Koch and others 1988). Raw material for the proposed plant would come from regeneration cuttings, sanitation-salvage operations, and preventive thinning treatments. Some of the material would be used in the manufacture of two products not heretofore produced in either the northwestern United States or western Canada, namely edge-glued lumber panels and fabricated pole joists. Both of these high-value products are made from dowels machined from subsawtimber-size lodgepole pine trees.

Table 2--Average mill-delivered cost of 3-in.- to 18-in.-diameter lodgepole pine. Costs include felling, skidding, loading, and hauling.[1]

Stem size	D.b.h.	Cost
(cu.ft.)	(in.)	($/cu.ft.)
1-2	3-4	.80-1.00+
2-10	4-8	.52- .80
10-30	8-12	.29- .52
30-70	12-18	.24- .29

[1]Costs were derived from Jackson and others (1984) based on the following assumptions: felling with a feller-buncher, 500-foot one-way skidding with a rubber-tired grapple skidder, and a 50-mile one-way hauling distance. These costs are averages based on a broad range of operating conditions.

A notable anomaly emerges in considering the feasibility of the proposed plant, and one that is central to the problem of utilization as it relates to reducing mountain pine beetle losses. Despite the large acreage of both older, stagnated stands and beetle-infested stands within the proposed procurement area for the plant (75-mile radius), available raw material supply may not be sufficient for the planned 20-year life of the mill. Concern about a dependable long-term supply may seem absurd in light of the ongoing beetle epidemic and existing 105,000 acre supply (Koch and others 1988) of stagnated, marginal sawlog, and dead sawtimber stands within the procurement area. In this situation, concerns about supply might be likened to the old saw "water, water, everywhere, but not a drop to drink." However, past regeneration cutting coupled with recent heavy cutting to recover dead and threatened trees may bump up against cumulative effect constraints, effectively limiting large-scale harvest well into the future. Thus, attempts to reduce losses to the mountain pine beetle through utilization may be stymied, despite both demand for the raw material and an excess of supply. The root of the problem at this point is no longer a biological or technical one, but rather a social and administrative one.

A fairly recent development in the field of harvesting technology, namely helicopter logging,

also has potential for reducing losses to the mountain pine beetle. Helicopters can be used for salvaging large-diameter, dead and threatened trees in steep terrain where visual constraints or road-building costs may prohibit conventional logging. However, most of the following requirements have to be met for this approach to be feasible for harvesting lodgepole pine (Kinghorn 1988; Sanders 1988):

1. Local demand for raw material must be strong.
2. Stumpage costs must be low.
3. Sale volume should be 500 thousand board feet (MBF) or greater.
4. Harvested trees should average 9 to 10 inches in diameter or larger.
5. Flight distance from woods to landing should be one-half mile or less.
6. Small, maneuverable, and cheap helicopters (e.g., Lama) should be used rather than larger, costlier ones (e.g., Skycrane).

While helicopter logging has been used almost exclusively to harvest large-diameter, high-value trees (e.g., yellow pine [Pinus ponderosa Dougl. ex Laws.] for sawlogs; western redcedar [Thuja plicata Donn] for shakes), it has also been used in several specialized situations to salvage beetle-killed lodgepole pine in steep terrain. Harvest costs in the log deck typically range from $100 to $160/MBF, which is similar to skyline logging with intermediate supports (Sanders 1988). Helicopter logging appears to have increased potential in the future as managers become more aware of the specific timber sale design features necessary for its successful application.

SUMMARY

Management focus during a mountain pine beetle epidemic is necessarily on salvaging mortality, since the "window of opportunity" for utilizing dead trees for most high-value products is less than five years. However, the long-term solution to the beetle problem will probably not come until there are sufficient utilization opportunities and product values for the smaller material removed in preventive silvicultural treatments. Regeneration cutting aimed at liquidating stagnated stands or breaking up extensive areas of uniform age classes, or intermediate treatments aimed at increasing tree vigor, will only be carried out on a broad scale if such treatments can pay their own way. Even then, as a recent example in northwestern Montana has shown, the ability of managers to capitalize on large-scale utilization opportunities to reduce mountain pine beetle losses may depend more on social and administrative factors than on technical or biological ones.

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EFFICACY OF VERBENONE FOR PREVENTING INFESTATION OF HIGH-VALUE LODGEPOLE PINE STANDS BY THE MOUNTAIN PINE BEETLE

Richard F. Schmitz

ABSTRACT: Results from experimental deployment of the mountain pine beetle (MPB) (Dendroctonus ponderosae Hopkins) semiochemical verbenone, an antiaggregative pheromone component, suggest it may be useful for preventing or suppressing MPB infestations in high-value lodgepole pine stands (Pinus contorta var. latifolia Dougl.). Field measures of the response of MPB to funnel traps baited with the standard MPB lure (trans-verbenol, exo-brevicomin, and myrcene) in Utah showed a 98 percent reduction in MPB trapped when verbenone was added. When used experimentally to protect 1-ha lodgepole pine stands in Idaho from further MPB infestation, the treated stands had an average reduction of 48.6 percent in the number of infested trees. Comparable findings have resulted from similar tests conducted in Canada.

INTRODUCTION

There is an obvious need for environmentally acceptable suppression strategies that protect high-value lodgepole pine stands, such as those in travel influence zones, campgrounds, and riparian areas, from infestation by the mountain pine beetle (Dendroctonus ponderosae Hopkins) (MPB). This need has prompted investigations to determine how semiochemicals like verbenone might be used to suppress MPB populations. As a result, the effectiveness of suppression strategies utilizing synthetic semiochemicals to manipulate dispersing mountain pine beetle populations is being field tested to determine how these natural compounds should be deployed to prevent infestation of high-hazard stands (Amman and others, in press; Borden and others 1983; 1987; Lindgren and others, in press). To that end, representatives of the U. S. Environmental Protection Agency (EPA) agree that semiochemicals may be preferable to conventional pesticides in the management of insect pests and encourage their development and use (Booth 1988).

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Earliest efforts to exploit semiochemicals for suppression purposes concentrated on the attractive components that guide flying beetles to suitable hosts. As a result, most field tests were designed to evaluate the most effective deployment of these attractive elements to lure and concentrate beetles in stands targeted for harvesting. Results revealed that beetle populations attracted to baited stands often "spilled over" into surrounding unbaited stands that land managers intended to protect (Furniss 1972). At the same time, field tests to evaluate the function of each newly isolated component in a specific pheromone bouquet revealed that bark beetle pheromone systems contained an anti-aggregative component (Borden 1982). In general, these components appear to function as a mask that terminates response to the attractive elements, thereby ensuring that the density of attack does not exceed the threshold for optimum brood survival (Borden and others 1987).

SOURCE AND EFFECTIVENESS OF MOUNTAIN PINE BEETLE ANTIAGGREGATIVE COMPONENTS

Verbenone was identified and first isolated from the mountain pine beetle pheromone complex, using the hindguts of newly emerged and feeding female MPB, by Pitman and others (1969). It was also identified from air passed over emergent male/female pairs (Rudinsky and others 1974). The first evidence that verbenone had antiaggregative properties resulted from laboratory and field bioassays that showed (-)-verbenone inhibited MPB response to selected host- and beetle-produced volatiles (Ryker and Yandell 1983). Additionally, four other pheromone components isolated from the MPB pheromone have at times exhibited anti-aggregative properties. These include endo- and exo-brevicomin released by attacking males (Libbey and others 1985; Rudinsky and others 1974; Ryker and Rudinsky 1982), frontalin produced by feeding males (Libbey and others 1985; Ryker and Libbey 1982), and verbenone and pinocarvone produced by feeding beetles of both sexes (Libbey and others 1985).

Recent field tests in British Columbia (Borden and others 1987), using two release rates of endo-brevicomin, failed to confirm the concentration-dependent multifunctional attractive and antiaggregative qualities reported by Ryker and Rudinsky (1982). Similarly, field tests in Oregon (Libbey and others 1985) failed to substantiate the multifunctional properties of exo-brevicomin, confirming its antiaggregative qualities at high

release rates but failing to demonstrate attractive properties at low rates. When used as a tree bait, it elicits a host-specific response. On western white pine, Pinus monticola Dougl. ex. D. Don, it inhibited MPB attack (McKnight 1979; Pitman and others 1978), but on lodgepole pine, P. contorta var. latifolia Dougl., attack was enhanced (Borden and others 1983; McKnight 1979). Field tests of frontalin in Oregon revealed it had antiaggregative effects at high concentration (Rudinsky and others 1974) but induced attack on lodgepole pine in Idaho (Chatelain and Schenk 1984). Trapping experiments in which pinocarvone was added to MPB lure reduced the catch by 50 percent (Libbey and others 1985).

ROLE OF VERBENONE IN HOST COLONIZATION

Results to date suggest the primary antiaggregative semiochemical that regulates MPB response to its host is (-)-verbenone. It has been recorded from three sources: (1) female beetles (Pitman and others 1969), (2) auto-oxidation of alpha pinene to cis- and trans-verbenol, then to verbenone (Hunt and others 1988; Lindgren and Borden, these proceedings), and (3) oxidation of cis- and trans-verbenol by microorganisms (primarily yeasts) associated with the beetle (Hunt and Borden, in press; Lindgren and Borden, these proceedings).

A complete understanding of the interaction between pheromone components that regulate MPB host selection behavior requires all components be identified and tested at appropriate concentrations in the field. To date, 33 semiochemicals have been isolated from the beetle (Lindgren and Borden, these proceedings), and they often elicit conflicting responses from the beetle, depending on test concentrations and methods of deployment (Lindgren and Borden, these proceedings). The following conceptual model proposed by Borden and others (1987) summarizes what is known about the sources of verbenone, the onset of production in relation to the sequence of attack, and its probable role in regulating the duration and density of attack.

At the onset of attack by female MPB, volatiles (including the host monoterpenes alpha-pinene and myrcene together with female-produced trans-verbenol) attract additional beetles to the tree. As males reach the tree, they release exo-brevicomin, which initially attracts primarily females, thereby enhancing the level of attraction. As additional males colonize the tree, concentrations of exo-brevicomin increase and are augmented by the male-produced antiaggregant, frontalin. Simultaneously, concentrations of the aggregative components, trans-verbenol, and the host monoterpenes begin to decline. At this stage in colonization, it is believed verbenone levels produced by (1) auto-oxidation of the host monoterpene, alpha pinene, to cis- and trans-verbenol and then to verbenone, and (2) by conversion of cis- and trans-verbenol by microorganisms, reach concentrations that deter additional beetles from attacking the focus tree. The effect of these antiaggregants is to limit attacks to a density that ensures survival of the ensuing brood.

VERBENONE FIELD TESTS

Reducing Response to Attractive Traps

During the summer of 1986, entomologists from the Intermountain Research Station, in cooperation with personnel from Phero Tech Inc., Vancouver, BC, conducted tests in the Wasatch National Forest in Utah to compare the number of MPB attracted to the standard MPB lure (trans-verbenol, exo-brevicomin, and myrcene), with and without verbenone (Schmitz and McGregor, in press).

Methods--The MPB lure contained trans-verbenol, exo-brevicomin, and myrcene eluted at 2 mg/24 h, 0.2 mg/24 h, and 18 mg/24 h at 25 °C, respectively. Verbenone was contained in the standard plastic bubble cap and released at 5 mg/24 h/capsule at 25 °C. The test was conducted in a mature lodgepole pine stand surrounded by stands in which MPB populations were building to outbreak levels. The eight test blocks were 30 m square and were separated from one another by 30-m intervals. Funnel traps were hung at each of the four corners of a block. The four treatments--MPB lure, MPB lure with verbenone, verbenone alone, and empty trap--were randomly assigned to each of four positions. Effectiveness of verbenone as an antiaggregant was assessed by the number of MPB caught by treatment.

Results--A total of 1,130 MPB were trapped by the four treatments. Results by block are given in figure 1. The number and percentage caught by treatment are tabulated below:

	Number	Percent
MPB lure alone	1,083	95.8
MPB lure with verbenone	19	1.7
Verbenone alone	7	0.6
Unbaited trap	22	1.9
Total	1,130	100.0

The number of MPB responding to the MPB lure with verbenone was significantly less than to the MPB lure alone. Overall, the addition of verbenone to the synthetic MPB lure reduced the catch by 98 percent.

A field test of MPB response to synthetic semiochemicals in British Columbia revealed that when verbenone was released in funnel traps at 1 or 5 mg/24 h in the presence of the attractive synthetic MPB lure (trans-verbenol, exo-brevicomin, and myrcene), it reduced the response of males approximately 75 percent. Although not statistically significant, the reduction in female response followed a similar trend (Borden and others 1987).

Protecting Stands from Infestation

The encouraging results from the studies that used verbenone to suppress catch of MPB in traps prompted a second set of tests to determine the efficacy of verbenone for reducing MPB infestation

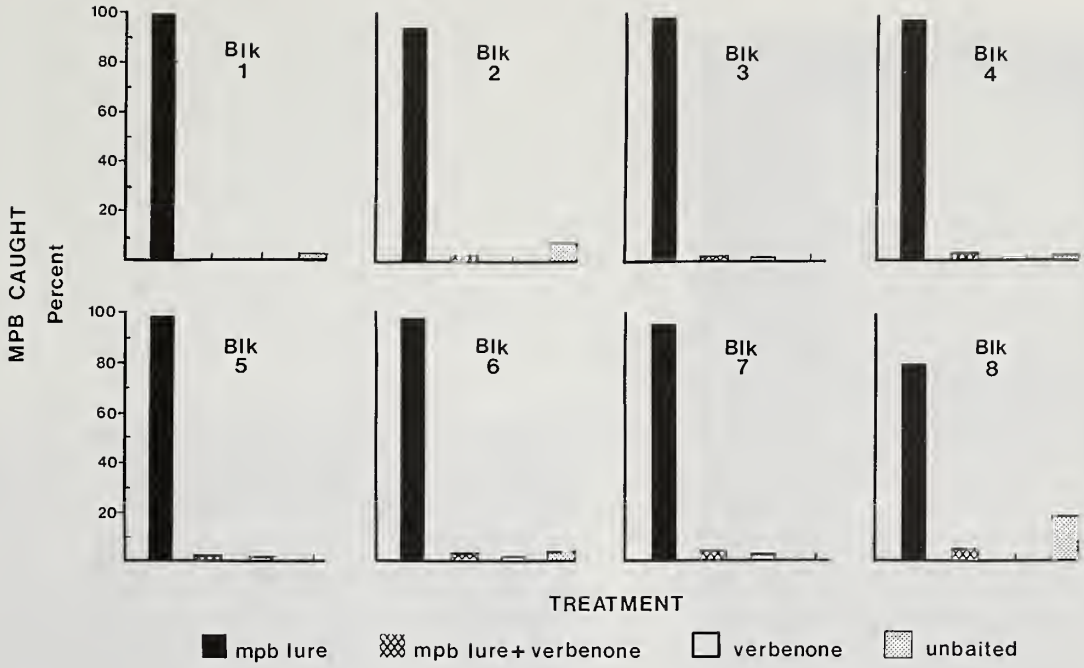


Figure 1--Number of MPB responding to funnel traps baited with synthetic MPB lure and the antiaggregant verbenone, alone and in combination, in eight test blocks, Wasatch National Forest, 1986.

in selected stands of lodgepole pine (Amman and others, in press). The test was conducted in the Sawtooth National Recreation Area, ID, while similar tests by Lindgren and others were being conducted in British Columbia, during 1987.

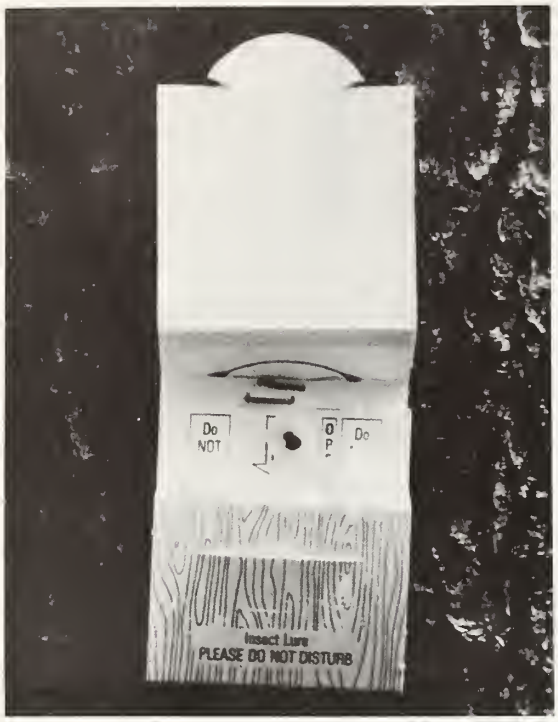
The Sawtooth National Recreation Area was selected for the study because MPB populations in that area were rapidly increasing, providing an opportunity to test the effectiveness of verbenone for preventing infestation of high-value trees in campgrounds, near administrative sites, wildlife sites, and near summer homes. Lodgepole pines 15.2 cm and larger diameter at breast height (d.b.h.) averaged 20 cm d.b.h. and 144 years old. The stand consisted of 75 percent lodgepole pine; the remainder was mostly Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) and a few quaking aspen (*Populus tremuloides* Michx.). The ratio of infested trees from 1985 to 1986 was 1:8. A survey through the main part of the infestation revealed 57 newly infested trees per hectare. Eighty percent of these were 20 cm and larger d.b.h., those sizes of trees in which MPB reproductive success is best (Cole and others 1976).

Methods--Verbenone was eluted from the standard plastic bubble cap at 5 mg/24 h/capsule at 25 °C in the presence of the MPB tree bait. Constituents of the MPB lure were the same as those used in the earlier trap tests (*trans*-verbenol, 2 mg/24 h; *exo*-brevicomin, 0.2 mg/24 h; and myrcene, 18 mg/24 h, at 25 °C). Treatments consisted of (1) MPB tree lure, (2) verbenone, (3) MPB tree lure and verbenone, and (4) check. Each treatment was applied individually to 1-hectare blocks and replicated four times. Five MPB tree baits were used in each baited block.

The cardboard containing the MPB lure was stapled 2 m above ground level on the north side of a lodgepole pine 20 cm or larger d.b.h. (fig. 2a). MPB tree lures were distributed in the center of the block and at each cardinal direction from the center, approximately 20 m from the outside boundary of the block.

Verbenone-treated blocks had 100 verbenone bubble capsules obtained from Phero Tech Inc., Vancouver, BC (chemical purity 98.6 percent; optical purity ee = (-)72 percent), spaced in a grid pattern approximately 10 m apart. The capsules were stapled to the north sides of trees 2 m above ground (fig. 2b). In the blocks treated with MPB tree bait plus verbenone, baits and verbenone bubble capsules were distributed as described for each alone. Check blocks were untreated.

All lodgepole pines larger than 15.2 cm d.b.h. were examined in each block to determine the d.b.h. and number killed for the years 1986 and 1987. Treatment effects were assessed by comparing the percentage of all lodgepole pine 15.2 cm d.b.h. and larger in each block that was infested by MPB in 1987. Because stand characteristics have been shown to affect mountain pine beetle infestation behavior (Cole and Amman 1980), stand measurements were made on five 10-factor basal area plots in each treatment block. Plots were positioned so overlap did not occur--one at block center and one in each corner. All trees 12.7 cm d.b.h., regardless of species, were tallied. These data were used to calculate percentages of trees that were lodgepole pine, average d.b.h. of lodgepole pine, stand basal area, and crown competition (Krajicek and others 1961) to be analyzed by ANOVA for differences among treatments.



A

B

Figure 2--Dispensers from which MPB lure and verbenone were released: (A) paper container with plastic vials containing the three-component attractive lure, (B) verbenone bubble cap with paper sunshade to limit exposure to solar radiation.

Results--A significant difference in percentages of infested trees among treatments was shown by ANOVA. Blocks having MPB baits only had significantly more mass-attacked trees than other treatments. The effect of verbenone is apparent.

The average percent of lodgepole pine infested by mountain pine beetles in blocks treated with mountain pine beetle tree baits and verbenone is shown here:

	MPB tree bait present	MPB tree bait absent
Verbenone present	7.425	0.875
Verbenone absent	24.425	3.275

Verbenone in the presence of mountain pine beetle tree bait resulted in a 2.3-fold reduction in infested trees.

An examination of the percent change in numbers of MPB-infested trees between 1986 and 1987 for the four treatments shows that only in verbenone-treated blocks did an average reduction occur (-48.6 percent). However, despite the overall reduction, an increase occurred in three of the four blocks. Check stands showed either no change or a decline in three of the four blocks, with a large increase in the fourth block. However, the average increase was 64.7 percent from 1986 to 1987. Changes in infestation in verbenone-treated and check blocks were small when compared to baited blocks, which showed an average infestation increase of 2,575 percent. Blocks containing MPB baits and verbenone had an average infestation increase of 418.8 percent. The large difference in MPB infestation between MPB bait blocks and MPB bait plus verbenone blocks is considered due to the effect of verbenone. This suggests verbenone has considerable potential for reducing infestation of lodgepole pine stands, a conclusion also reached from tests by Lindgren and others (in press) in British Columbia.

Further, infestation differences probably were not related to differences in stand characteristics, since ANOVA failed to detect differences among treatments in percent of trees that were lodgepole pine, d.b.h. of lodgepole pine, basal area, and crown competition factor.

Discussion--Although verbenone-treated blocks had significantly fewer infested trees than blocks with MPB baits, the question remains: Would verbenone-treated stands have shown the significant reduction in MPB infestation without the accompanying source of attraction provided by

MPB baits? MPB dispersal may have been altered by the presence of pheromone baits, thereby affecting distribution among the other treatments. At this population level (3.7 infested trees per hectare in 1986), beetles from surrounding stands were probably drawn into the study blocks as indicated by the large increase in infested trees in 1987 (27.5 trees per hectare), especially in blocks containing MPB baits, which had 80.3 infested trees per hectare in 1987. How beetles would respond at higher population levels, or in the absence of the synthetic attractants, could not be deduced from the study. The investigators suggest that MPB may be attracted to the general area of verbenone-treated trees or stands and then infest trees where verbenone concentrations are low. Thus, while preventing infestation of treated trees and stands, infestation level of surrounding stands may be increased. Additional tests are under way to clarify this point.

OUTLOOK

The research results described here point to a growing understanding of the effects of semiochemicals, especially the antiaggregative components, on MPB host selection and aggregation behavior, and how they may best be integrated with existing suppression strategies once registered for operational use. Before these chemical messengers can be exploited to the fullest extent, it is likely several major gaps in our knowledge base regarding semiochemical deployment will need to be filled. These include (1) a knowledge of the structure of odor plumes and the effect topography and stand microenvironment have on their concentration and movement, (2) an understanding of the inherent differences in response between individual beetles in a population and between different population levels, (3) knowledge of the effects of environment on dispersion patterns of emerging adults, and (4) response of associated insects.

Even though this knowledge is lacking, test results obtained to date suggest that verbenone has the potential to prevent MPB infestations from reaching unacceptable levels in high-value lodgepole stands. Further, its potential for preventing rather than limiting the level of infestation would likely be enhanced if used in conjunction with synthetic MPB lures deployed to attract the beetle to traps or stands away from the area to be protected. At this point, test results suggest that verbenone has promise as an environmentally acceptable tool that can be incorporated with other strategies for preventing or suppressing MPB infestations, and therefore warrants the testing needed to determine how it can be deployed most effectively.

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MOUNTAIN PINE BEETLE POPULATION MANIPULATION STRATEGIES--PAST SUPPRESSION PRACTICES

Eugene D. Lessard

ABSTRACT: Suppression of mountain pine beetle is a viable strategy when implemented at the stand level in conjunction with ongoing vegetation management and is designed to protect a high value resource for a short period of time. There is a need to evaluate all management strategies for mountain pine beetle using an orderly process. Decision analysis is one such process that has demonstrated its utility in pest management.

Before I get into suppression, I would like to define a few terms. A mountain pine beetle EPIDEMIC occurs over an extensive area and consists of a matrix of INFESTATIONS at the stand level. At any one time in an epidemic, an infestation in a stand may be in the epidemic, increasing, outbreak or declining phase. Stands themselves have varying levels of susceptibility which contribute both to the probability of an infestation occurring and to the expected level of infestation. Not all stands become infested and participate in an epidemic. In fact, not all highly susceptible stands participate in a given epidemic.

The history of mountain pine beetle suppression is marked by strategies that were directed at an epidemic and were applied too late in the epidemic cycle at great expense in both dollars and man power. How often have we sent out the cry for action when massive amounts of tree mortality dotted the landscape? How often have we treated thousands of infested trees for three to five consecutive years only to see a general deline in populations in treated and untreated areas alike? How often have we viewed this decline and said "see, control works?" The reality of mountain pine beetle suppression is that we are very effective at what I call the "Visine treatment". We CAN get the red out. Other than "getting the red out" what have we accomplished with mountain pine beetle suppression programs? I'm afraid that most of our accomplishments have a negative connotation. We've convinced a large portion of the public, ourselves included, that suppression is a viable strategy over large expanses of forested acres. We've disrupted management plans and effectively delayed ongoing vegetation management that could have reduced stand susceptibility to infestation. We've neglected the resource management objectives of the land manager by implying that all infestations are "bad" and must be suppressed. A line in a song by Burt Reynolds best sums up our accomplishments. He sings "let's do something cheap and superficial". Superficial? No doubt! Cheap? Not in dollars and cents or manpower! Suppression costs have escalated from $1.50 per tree in the mid 1970's to $20.00 a tree in 1985. However, cheap in that we have effectively mitigated the land manager's and the public's concern - we got the red out! - without addressing the real and often controversial problem - and epidemic of mature trees.

Our accomplishments in insect suppression are akin to our accomplishments in fire suppression. We've had some real success in suppressing defoliator populations nationwide. The result has been an overall increase in the age of the forest, increase in offsite tree encroachment, increase in the progression of forest succession and, an increase in the overall susceptibility of the forest to insects and diseases. We've also had real success in suppressing fires in the past. By doing so we've increased the average age of the forest, increased offsite encroachment, increased the progression of succession and increased the overall susceptibility of the forest to all insects and diseases. Indirectly mountain pine beetle suppression has produced the same results by negatively impacting ongoing vegetation management. As a consequence, our ability to suppress insect epidemics and put fires out is declining rapidly even as our technology continues to advance.

There is a need to evaluate management strategies in an orderly process. By what process do you value the various alternative strategies? Using decision analysis, a procedure was developed to match management strategy to a land classification system (Freeling and Seaver 1980). The procedure first developed a land classification system based on the following criteria:

1. Stand risk to mountain pine beetle infestation
   a. moderate to high
   b. low
2. Land accessibility or operability
   a. accessible
   b. inaccessible

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3. Tree value

a. high
b. low

From this eight land classifications were constructed, eg. moderate to high risk, accessible and, high value. The second part of this procedure involved the development of the following management strategies:

1. Thinning of stands

2. Preventive spraying

3. Favoring tree species other than the host species

4. Direct control actions taken to reduce the beetle population

5. No action

Using a range of current costs and values, each strategy was evaluated economically for each individual land classification. The viability of each strategy was then examined in the context of the land classification system and a preferred strategy developed. In addition, five major premises were developed during this process:

1. All host type, regardless of ownership can be stratified into land classification units.

2. Mountain pine beetle cannot be controlled by any method over extensive areas of land.

3. Management and control of mountain pine beetle is viable in restricted areas of type having relatively high value.

4. The ideal strategy for managing mountain pine beetle is to intensively manage the host type, thereby preventing outbreaks from occurring.

5. Prevention is a viable strategy only in moderate to high susceptible stands or in low susceptible condition in the near future. This thumb nail sketch of decision analysis is used here to demonstrate one strategy for managing mountain pine beetle in an orderly process. Not all strategies make sense under all conditions. The process can be made dynamic so that, as conditions change strategies can be reexamined and new preferred strategies developed. Gene Amman, Intermountain Research Station, is in the process of developing a decision model for mountain pine beetle. Once the framework of the model is developed, other bark beetle scenarios could be developed.

Is suppression ever a viable strategy for dealing with mountain pine beetle? The answer is clearly YES! Suppression makes sense when implemented at the stand level and designed to protect a valuable resource for a short period of time - 1 or 2 years. An example of a viable suppression strategy would be the use of preventive sprays with salvage logging in an infested campground to protect high value trees from immediate attack while preparing to implement a vegetation management plan to reduce overall stand susceptibility. Another example might be the use of pheromone baited trap stands or trees to reduce beetle pressure on high value sawlogs in an ongoing timber sale. The scenario seems clear. If we're going to attempt suppression it must be done at the stand level and in conjunction with ongoing vegetation management.

Knowing that suppression is ineffective over large forested areas, most entomologists realize the need to prevent infestations or, more realistically, to reduce the impact on the forest resource given an infestation will occur in the future. Forest Plans are delineating areas on the ground and addressing the management objectives for those areas. Management prescriptions are placing emphasis on particular resource needs for an area and outlying silvicultural practices to attain the stated objectives. Entomologists are providing input into the second round of the Forest decisions of the land manager.

Nationwide we have 56.6 million acres of host type susceptible to mountain pine beetle infestation. Annually, 4.3 million acres is at epidemic levels. At this rate all susceptible acres will be impacted over the next 13 years. However, not all of these acres will be negatively impacted. Forest plans must identify those acres that will be negatively impacted; strategies for reducing the impact; and, most important of all, the probable scenario if strategies are not implemented. Forest plans must also address the consequences of the "no action" alternative. This alternative too often implies that the vegetation will remain static over time.

The future is both positive and exciting. In the past few years entomologists and pathologists have taken the lead in developing the tools of silviculture as a means of attacking the cause and not the symptom of insect infestation. We have established long term studies to demonstrate the use of silviculture in pest management. Many of these demonstrations are just now yielding valuable information which should be documented in the forest planning process and implemented on the ground. We have entomologists and pathologists being trained and certified as silviculturists and accepted as knowledgeable specialists. We have a National Forest Health Initiative which has the stated objective of developing "a strategic plan to enhance and maintain the health of the Nation's forests which will be implemented through Forest Service programs and authorities." We have the opportunity to make a quantum leap in forest pest management. Let's not miss our chance.

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SEMIOCHEMICALS OF THE MOUNTAIN PINE BEETLE (*Dendroctonus ponderosae* Hopkins)

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ABSTRACT: Two decades of research on the chemical ecology of the mountain pine beetle has yielded four semiochemicals of real or potential value to forest managers. Aggregation of beetles to baited trees or artificial traps can be achieved with a mixture of *trans*-verbenol, *exo*-brevicomin and myrcene. Losses of lodgepole pine to mountain pine beetle were reduced significantly by the antiaggregation pheromone verbenone, even when challenged by attractive tree baits, in experiments in Idaho and British Columbia. New candidate semiochemicals have recently been identified and will be field tested in 1988 and 1989.

INTRODUCTION

Since the first discovery of the aggregation pheromone of *Ips paraconfusus* Lanier (Silverstein and others 1966), a multitude of semiochemicals have been identified from bark beetles in North America and Europe (Borden 1977, 1982). Extensive research has been conducted on the semiochemical complex of the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, over the last 20 years. In this paper we will present an overview of the most significant mountain pine beetle semiochemicals, and their role in the population dynamics of the mountain pine beetle and its insect associates.

Definition

Semiochemicals are naturally occurring compounds which are produced by an individual of a species and elicit a behavioral response in other individuals of the same or different species. Depending on the receiving and emitting species and whether the response is of benefit to the emitter or the receiver, a given semiochemical may be referred to as a pheromone, kairomone or allomone (Nordlund 1981). Other terms are recognized as well, but for this overview these three will suffice. Nordlund (1981) defined these terms as:

- Pheromone: "a substance secreted by an organism to the outside that causes a specific reaction in a receiving organism of the same species."

- Kairomone: "a substance produced or acquired by an organism that, when it contacts an individual of another species in the natural context, evokes in the receiver a behavioral or physiological response that is adaptively favorable to the receiver but not to the emitter."

- Allomone: "a substance produced or acquired by an organism that, when it contacts an individual of another species in the natural context, evokes a response that is adaptively favorable to the emitter but not to the receiver."

As pointed out by Borden (1988a) these are functional designations, so that any given compound may have more than one function, e.g. a semiochemical could act as a pheromone intra-specifically and as a kairomone inter-specifically.

Pheromones may have different functions, e.g. they may be attractants or repellents. Bark beetle pheromones serve as aggregation pheromones, i.e. pheromones which attract members of both sexes, normally to a suitable breeding resource, and epideictic (antiaggregation) pheromones, which serve to prevent over-utilization of the same breeding resource.

THE ROLE OF SEMIOCHEMICALS IN MOUNTAIN PINE BEETLE POPULATION DYNAMICS

Semiochemicals influence mountain pine beetle population dynamics directly and indirectly. Borden (1988a) described five basic ways of action. Two of these affect mountain pine beetles directly as aggregation or antiaggregation pheromones, while the remaining three have indirect effects.

Direct Effects

Aggregation--Pioneer females identify susceptible trees by kairomonal, visual and/or gustatory cues. As the attack is initiated the combined effect of the female-produced aggregation pheromone *trans*-verbenol (Pitman and others 1968, 1969) and host kairomones, i.e. monoterpenes such as *alpha*-pinene (Pitman 1969)

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or myrcene (Billings and others 1976; Borden and others 1983), attract other females and males to the tree. Males joining the attacking females release exo-brevicomin (Rudinsky and others 1974; Borden and others 1983; Conn and others 1983), which attracts mainly females.

Antiaggregation and Switching--As a tree becomes occupied by beetles establishing their brood galleries, increasing concentrations of exo-brevicomin and frontalin from males act as antiaggregation pheromones (Rudinsky and others 1974; Borden and others 1987) while decreasing concentrations of female-produced trans-verbenol and host volatiles reduce the attractiveness of the tree (Pitman and Vite 1969). In white pine stands, exo-brevicomin appears to serve as an antiaggregation pheromone even at concentrations which induce attraction in lodgepole pine stands (McKnight 1979). Furthermore, autoxidation and conversion by microorganisms of cis- and trans-verbenol to verbenone (Hunt and Borden 1988a; Hunt and others 1988) generate a strong anti-aggregation message, ensuring that overcrowding of the resource does not take place. Incoming females land away from the source of the anti-aggregation pheromones, thereby spreading the attack along the bole of the tree and eventually leading to the switching to adjacent trees, where the process is repeated (Geizler and Gara 1978; Berryman 1982).

Indirect Effects

Aggregation of Competing Species--Several bark beetle species are associated with mountain pine beetles (Amman 1975; Furniss and Carolin 1977). Although poorly documented, some species, e.g. Ips pini (Say), compete directly with the mountain pine beetle for breeding resources under some circumstances. Ips beetles may locate mountain pine beetle infested trees by kairomones produced by the beetles and/or the tree, and attack available portions of the trunk. Normally this would limit Ips-attacks to parts of the tree with thin phloem, but if the mountain pine beetle attack density is low Ips pini may attack the entire tree.

Inhibition of Aggregation by Competing Species--Mountain pine beetle males produce S-(+)-ipsdienol, which in parts of the range of Ips pini is antagonistic to the attractiveness of the aggregation pheromone R-(-)-ipsdienol (Hunt and others 1986). Mountain pine beetles also produce myrcenol, which has been shown to inhibit the response by Ips pini to traps baited with racemic ipsdienol (D. Miller[1], pers. comm.). It is likely that these compounds, which do not appear to affect mountain pine beetle aggregation, are produced to prevent competition for breeding resources by Ips pini (Hunt and others 1986).

Aggregation of Insect Associates--Predators, parasites and other insect associates of the mountain pine beetle may utilize the host and/or beetle produced kairomones to find a tree under attack (Borden 1988b). Such a tree may provide both food and breeding opportunities for some of these insects, e.g. the predatory clerid beetle Enoclerus sphegeus.

SEMIOCHEMICALS USED TO MANIPULATE POPULATIONS OF THE MOUNTAIN PINE BEETLE

A large number of compounds have been identified from the mountain pine beetle (table 1). Only a few of these have been found to have sufficient activity to warrant development for operational use.

trans-Verbenol is produced mainly by feeding females (Pitman and others 1968, 1969) and to a lesser extent by autoxidation of alpha-pinene (Hunt and others 1988). This aggregation pheromone is released after the female beetle starts boring into the tissues of the host tree, with maximum production occurring 12-18 hours after the female reaches the inner bark (Pitman and Vite 1969). When combined with host volatiles, trans-verbenol will induce attacks on baited trees, and it will attract limited numbers of mountain pine beetles to artificial traps or field olfactometers (Pitman 1971; Billings and others 1976; Conn and others 1983). trans-Verbenol is universally attractive in forests of white, ponderosa, and lodgepole pines (McKnight 1979).

exo-Brevicomin is mainly produced by feeding male mountain pine beetles (Pitman and others 1969). Its function is concentration-dependent (Rudinsky and others 1974; Borden and others 1987), and evidently varies with host species as well (McKnight 1979). In lodgepole pine forests exo-brevicomin enhances attacks on trees baited with trans-verbenol and a host volatile, and when released at low rates (0.05 mg/24 hrs) it improves catches of females in traps (McKnight 1979; Borden and others 1983; Conn and others 1983; Borden and others 1987). At higher release rates (0.5 and 5 mg/24 hrs) exo-brevicomin does not affect catches of females in traps, whereas male catches are reduced as compared to catches by trans-verbenol and myrcene. Ryker and Rudinsky (1982) reported that exo-brevicomin disrupted aggregation to trans-verbenol in Oregon, while Libbey and others (1985) could not establish any effect. In white pine stands in Idaho, McKnight (1979) found that exo-brevicomin disrupted aggregation to trees baited with trans-verbenol and alpha-pinene.

Myrcene is a relatively minor component of pine resin, but was found to be the best monoterpene synergist for trans-verbenol in ponderosa pine stands in Washington (Billings and others 1976) and in lodgepole pine stands in British Columbia

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Table 1--Semiochemicals isolated from the mountain pine beetle and/or tested in laboratory or field bioassays

Semiochemical	Activity	Selected References
trans-Verbenol	Attractive in traps and on trees when combined with a host volatile. (-)-Enantiomer active, antipode inactive.	Pitman and others 1968 McKnight 1979 Libbey and others 1985 Borden and others 1987
cis-Verbenol	Detected in trace quantities.	Pitman and others 1969
Verbenone	Detected in trace quantities in females. (-)-Enantiomer active in lodgepole pine. Mainly produced by autoxidation and microbial oxidation of alpha-pinene.	Pitman and others 1969 Ryker and Yandell 1983 Hunt and others 1988
exo-Brevicomin	Multifunctional pheromone. At low release rates synergizes trans-verbenol lodgepole pine. Inhibitory in white pine.	Pitman and others 1969 Rudinsky and others 1984 McKnight 1979 Borden and others 1987
endo-Brevicomin	Antiaggregation pheromone. No effect in lodgepole pine in British Columbia (unpublished data in Borden and others 1987).	Rudinsky and others 1974 Libbey and others 1985 Borden and others 1987
Frontalin	Multifunctional pheromone. Inhibitory at high release rates. Induces attacks on trees.	Ryker and Libbey 1982 Chatelain and Schenk 1984
Ipsdienol	S-(+)-ipsdienol produced by males. Inhibitory in trap bioassays.	Libbey and others 1985 Hunt and others 1986 Hunt and Borden 1988b
Acetone	In fresh resin of ponderosa pine. Inactive in trap bioassays.	Billings and others 1976 Libbey and others 1985
Ethanol	Inactive in field test. Arrestant in laboratory.	Libbey and others 1985 Syed and Graham 1987
Acetophenone	Attractive in laboratory bioassay. No effect in one field test.	Conn and others 1983
alpha-Pinene	Synergistic host volatile. Precursor of trans-verbenol.	Pitman 1971 McKnight 1979
beta-Pinene	Slightly synergistic with trans-verbenol on trees.	Borden and others 1983
Myrcene	Superior synergist in ponderosa and lodgepole pine.	Billings and others 1976 Borden and others 1983
beta-Phellandrene	Major monoterpene of lodgepole pine. Slightly synergistic in traps.	Conn and others 1983
3-Carene	Synergistic with trans-verbenol in traps and slightly so on trees.	Conn and others 1983 Borden and others 1983
Terpinolene	Synergistic with trans-verbenol in ponderosa pine, slightly so in lodgepole pine.	Billings and others 1976 Borden and others 1983
3-Caren-10-ol	Attracted more males in traps in B.C. and Oregon (contradiction between text and table in Libbey and others 1985).	Conn and others 1983 Libbey and others 1985

(con.)

Table 1--Continued

Semiochemical	Activity	Selected References
Myrcenol	Inhibitory tendency. Produced by males.	Conn and others 1983 Hunt and others 1986
2-para-Menthen-7-ol	Slightly synergistic with trans-verbenol and myrcene.	Conn and others 1983
trans-Pinocarveol	Isolated from fed beetles, but no apparent activity.	Libbey and others 1985
Pinocarvone	Reduced trap catches.	Libbey and others 1985
Borneol	Isolated from fed beetles.	Libbey and others 1985
Terpinen-4-ol	Isolated from fed beetles.	Libbey and others 1985
alpha-Terpineol	Isolated from fed beetles.	Libbey and others 1985
Myrtenol	Isolated from fed beetles.	Libbey and others 1985
Piperitone	Isolated from fed beetles, but no apparent activity.	Libbey and others 1985
Octanone	Isolated from fed beetles in sugar pine.	Libbey and others 1985
3,2-Methylcyclohexen-1-one	Isolated from beetles.	Rudinsky and others 1974
Diacetone-alcohol	Electrophysiological response.	Whitehead 1986
Camphene	Electrophysiological response.	Whitehead 1986
Limonene	Electrophysiological response.	Whitehead 1986
Bornyl acetate	Isolated from single beetles.	Gries and others 1988
4-Isopropylanisole	Isolated from single beetles.	Gries and others 1988

(Borden and others 1983; Conn and others 1983). Pitman (1971) originally identified alpha-pinene as the most attractive monoterpene in white pine stands in Idaho. McKnight (1979) found that (+)-alpha-pinene was the active enantiomer in white pine stands.

Verbenone was first identified as a trace compound in female mountain pine beetles (Pitman and others 1969). Hunt and others (1988) showed that verbenone is produced by autoxidation of trans- and cis-verbenol, and by oxidation of these compounds by yeasts associated with the beetles (Hunt and Borden 1988a). Ryker and Yandell (1983) showed that (-)-verbenone inhibits aggregation to attractive volatiles. When applied at a 10 x 10 meter grid in infested stands of lodgepole pine, verbenone reduced attacks even when challenged by attractive tree baits (Amman and others 1988; Lindgren and others 1988). However, verbenone did not totally prevent tree mortality in either of these studies.

CURRENT RESEARCH

Improved techniques for identifying candidate compounds from live individual, boring female beetles have been developed (Gries and others 1988), resulting in the identification of highly volatile compounds which may have a role in mediating the mass attacks on trees. Tests to assess the behavioral activity of these compounds will be conducted in 1988 and 1989.

CONCLUSIONS

The chemical ecology of the mountain pine beetle is complicated, involving a large number of semiochemicals stemming from the beetles themselves or from the host tree. In spite of two decades of research, it appears that the true nature of the semiochemical communication system of the mountain pine beetle has yet to be solved. Nevertheless, current knowledge has allowed development of tree baits consisting of trans-verbenol, exo-brevicomin and myrcene as an effective management tool in lodgepole pine stands (Borden and Lacey 1984; Borden 1988b) and

verbenone promises to be useful in some situations where high value stands need protection (Amman and others 1988; Lindgren and others 1988). If current research leads to a more powerful attractant, mass trapping may become a realistic tactic in the future.

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BAITING AND CUTTING TO MANAGE MOUNTAIN PINE BEETLE INFESTATIONS

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ABSTRACT: Semiochemicals have gained wide acceptance in the past 8 years. Operational projects have demonstrated that synthetically produced semiochemicals are an effective tool to augment management of mountain pine beetle in spot baiting, containment, and concentration of beetle populations. Analysis of data from baited and check stands in the Kootenai and Flathead National Forests (NF) shows baiting significantly changes the number of infested trees per acre. Tree diameter is statistically significant. The relative difference in infestation shows the 7-8.9 inch and 9+ inch DBH size classes incur larger changes in infestation rate than 5-6.9 inch DBH size classes. Habitat type group did not influence infestation rates in baited stands in the Kootenai NF but was statistically significant in the Flathead NF. Analysis of build-up ratios shows that baiting and habitat type group are statistically significant for stands in the Flathead NF, but only baiting, and not habitat type, affected build-up ratios in baited stands in the Kootenai NF. Mortality due to baiting depends on the percent of lodgepole pine in the 5-6.9 inch DBH classes in baited stands.

INTRODUCTION

The current cycle of mountain pine beetle (MPB) infestations in the western U.S. and provinces of Alberta and British Columbia began in the early 1970s (Van Sickle 1982; McGregor 1982). Epidemic infestations are present in lodgepole pine (LPP) forests of four western USDA Forest Service Regions and four of the six forest regions in the Province of British Columbia. The other two regions in British Columbia have some infestation (Hall 1985). Further, extensive areas of susceptible pine are at risk as MPB infestations continue to expand and new epicenters develop.

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Various management approaches to reduce or prevent pine losses have been discussed by several other participants during this symposium. Strategies to reduce stand susceptibility by creating a mosaic of age and size classes and develop species diversity over several decades are most desired. Short-term strategies of totally suppressing a mountain pine beetle outbreak are unreasonable and probably impractical (Hall 1985), because stand conditions conducive for outbreak development would remain unchanged. Therefore, infestations would recur as soon as control strategies ceased. Also, it may be unrealistic to say direct control is entirely inappropriate or useless (Hall 1985). Direct control practices in specific areas can slow the rate of expansion of beetle populations and tree mortality. Slowing developing infestations in selected areas will buy time for developing management plans and implementing long-term strategies. This should be considered when developing harvesting and silvicultural prescriptions for specific areas. Indirect practices depend on modifying stand conditions that are conducive to beetle population build-up. Eventually, harvesting stands before they become susceptible and developing age-class and species mosaics should limit infestations and tree losses.

Whether implementing short- or long-term management strategies, the use of pheromones can enhance the efficiency of various management programs.

Pheromones, more specifically aggregation pheromones (semiochemicals), have been tested since the mid-1970s in British Columbia and the western U.S.

Early tests using trans-verbenol with alpha-pinene, and sometimes with ethanol included, showed that attractiveness of these combinations although positive was less than expected. When combined with single-tree treatment, such as preflight treatment with contact insecticides, postflight treatment with arsenicals, and preflight treatment of infested trees with penetrating insecticides for brood reduction, there was marked reduction in subsequent attacks when compared to check areas (Hall 1985). However, it was necessary to refine the pheromone complex before the use of semiochemicals could be considered for operational stand baiting.

RECENT TESTING

Following several years of field trials and testing of various combinations of potential synthetic chemicals by researchers at Simon Fraser University, notably Dr. John Borden, a consistently effective aggregation semiochemical was designed from a combination of trans-verbenol, exo-brevicomin, and myrcene (PMG/STRATFORD Project Ltd. 1983).

These formulations have been further field tested. By 1982, the use of tree bait semiochemicals was judged acceptable on an operational basis to enhance the effect of treatment (green stand harvest and sanitation cutting) in management of mountain pine beetle (Hall 1985).

A proven technique for tree-baiting with semiochemicals is to contain and concentrate infestations prior to logging (Borden and others 1983b). Originally developed for the Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins (Pitman 1973), the technique was adopted for the mountain pine beetle. It is now used routinely as a prelogging treatment in high-hazard lodgepole pine stands in British Columbia (Borden and Lacey 1985).

Spot Baiting

Early detection of small spot infestations (up to 30 trees) and baiting two or more large-diameter trees should contain emerging beetle populations in the immediate vicinity (Borden and Lacey 1985). Following beetle flight, newly attacked trees can be removed by small sales, felled and burned, or felled and treated with chemicals. Direct control of developing small spot infestations can be expensive, but it can buy time until long-term management plans are implemented.

Grid Baiting

The tactic of baiting susceptible trees on a grid requires approximately two baits per acre. In smaller blocks or stands (up to 20 acres), baits are attached to large-diameter trees on a 50-meter grid, starting 25 meters in from the unit boundary. Beetles emerging from brood trees should be in close proximity to pheromone baits (Borden and others 1983a). Baits are applied prior to beetle flight and harvest of newly attacked trees or stands must be completed prior to beetle flight the following year.

Perimeter Baiting

The second method entails baiting trees 50 meters apart in two parallel lines, also 50 meters apart around the proposed block boundary (more than 20 acres). When groups of infested trees occur within the unit, grid baiting at 50 meters or closer, and baiting small infested groups, will further concentrate beetles within the cutting unit. Emerging beetles will be in close proximity to baits and the remaining population within the stand should either naturally find host trees or be contained by baits at the periphery of the stand. Both methods ensure that within stands either grid-baited or baited at the periphery, the dispersing beetles will fly into the attractant odor plume and respond upwind to a baited tree. This will result in mass attack and spillover into adjacent trees as the baited trees are mass attacked (Borden and others 1983a).

Tests in the Northern Region

Based on favorable results, by Borden and many others with management of mountain pine beetle, semiochemical baits were initiated in high-risk green and infested stands in the Northern Region of the USDA Forest Service (Montana and Northern Idaho) in 1984 and 1985. In 1984, approximately 7,090 MPB tree baits were applied at two/acre in lodgepole pine stands scheduled for logging in six National Forests (NF) and on Bureau of Indian Affairs (BIA) and Bureau of Land Management lands. Although baited and check stands were not surveyed systematically, general observations indicated baits worked well, particularly where beetle populations were not excessively high, and where susceptible trees remained for baiting and spillover.

In 1985, 6,950 tree baits were again applied at a rate of two/acre in 117 susceptible lodgepole pine stands in six National Forests and on BIA lands.

Stands baited in 1984 and 1985 were scheduled for harvest prior to beetle flight. Nearly all baited stands were logged prior to beetle flight both years. However, some were not logged due to sales being extended. Stands baited in 1984 that were not logged were rebaited in 1985. Stands baited in 1985 but not logged prior to beetle flight in 1986 were not rebaited because the Environmental Protection Agency stopped the use of tree baits.

During the 1985 season, data were collected from 71 baited stands and 29 check stands. Stands were surveyed, using 10 BAF Prism plots, and all trees 5 inches DBH and larger and tree mortality cause by year were recorded. It was not possible to survey all 117 stands baited in 1985 since many were logged soon following beetle flight.

The data are observations based upon number of beetle-infested trees per acre by DBH size classes (5-6.9 inches, 7-8.9 inches, and 9+ inches), in baited and check stands. Several measures of beetle infestation were used, depending on objectives of the analysis: (1) change in number of infested trees per acre by DBH size class and habitat type from pre- to posttreatment, (2) build-up ratio of infested trees pre- to posttreatment, and (3) percent lodgepole pine mortality as affected by

percentage of trees in the 6-7.9 inch DBH size classes prebaiting.

The change in number of infested trees per acre from pre- to posttreatment was computed as post-treatment infested trees per acre minus pre-treatment infested trees per acre. The build-up ratio was computed as infested trees/acre post-treatment divided by infested trees/acre pre-treatment. Two other variables used in this analysis are percent susceptible LPP in the 5-6.9 inch DBH class, and percent mortality. Percent LPP in the 5-6.9 inch DBH class was computed as the number of LPP in the 5-6.9 inch DBH class at the pretreatment measurement date, divided by the total number of susceptible LPP in the stand. Percent mortality was computed as the total number of LPP killed by beetles following baiting, divided by the total number of LPP > 5 inches DBH in the stand.

Methods

The primary statistical procedure used in this analysis is the ANOVA (analysis of variance). In addition, Scheffe's multiple comparison test was used to determine the sources of variation in terms of specific treatment combinations (Snedecor and Cochran 1980, p. 232). Scheffe's test was carried out by computing a two-sample "t" statistic and comparing the value to the critical "t" specified by the test. Unfortunately, Scheffe's test has little power when sample sizes are small, but it does provide a method of separating very large differences from the merely large differences. For this reason, the primary use of Scheffe's test in this analysis was to rank differences between treatment combinations, and not as a formal test.

The computed value of a test statistic is noted as statistically significant if the p value associated with the statistic is less than 0.05.

Distribution of Samples and General Trends

Table 1 displays by habitat type group the number of stands sampled on the Kootenai NF. Sample sizes were restrictively small for most habitat type groups. Table 2 displays stands surveyed by habitat type group for the Flathead NF. This sample was quite small for comparative purposes.

Two habitat type groups in each National Forest have enough representation for formal analysis. For the Kootenai NF, the first habitat type group is the warm-wet (w-w) habitat type group consisting of habitat types 290, 420, 470, 520, 530, 591, 592, and 571. The second habitat type group is the cool-wet (c-w) habitat type group consisting of habitat types 620, 660, 663, 670, and 740.

Table 1--Number of observations for baited check stands by habitat type group, Kootenai NF, Montana, 1985

Habitat Type Group Number	ADP code	Name	Number of Stands Check	Baited
1	250	Psme/Vaca	0	1
1	260	Psme/Phma	0	1
1	262	Psme/Phma	0	1
2	290	Psme/Libo	1	2
2	420	Pice/Clun	0	2
2	470	Pice/Libo	0	1
2	520	Abgr/Clun	0	1
2	530	Thpl/Clun	0	1
2	591	Abgr/Libo-Libo	1	1
2	592	Abgr/Libo-Xete	1	0
2	571	Tshe/Clun	1	0
3	620	Abla/Clun	0	2
3	660	Abla/Libo	0	7
3	663	Abla/Libo-Vasc	1	0
3	670	Abla/Mefe	1	9
3	740	Abla/Alsi	1	0
4	650	Abla/Caca	0	1
5	690	Abla/Xete	1	5
5	720	Abla/Vagl	0	1
6	730	Abla/Vasc	0	2

Table 2--Number of observations for baited and check stands by habitat type group, Flathead NF, Montana, 1985

Habitat Type Group Number	ADP Code	Name	Number of Stands Check	Baited
1	750	Abla/Caru	0	1
1	280	Psme/Vagl	0	1
1	290	Psme/Libo	0	1
1	730	Abla/Vasc	0	1
2	620	Abla/Clun	0	2
2	621	Abla/Clun-Clun	1	1
2	624	Abla/Clun-Xete	1	1
2	625	Abla/Clun-Mefe	4	4
2	660	Abla/Libo	3	1
2	662	Abla/Libo-Mefe	3	1
2	670	Abla/Mefe	0	2
3	640	Abla/Vaca	1	2
3	663	Abla/Libo-Vasc	0	1
3	690	Abla/Xete	1	5
3	692	Abla/Xete-Vasc	6	7
4	654	Abla/Caca	0	1
5	312	Psme/Syal	1	0

Table 3--Factors affecting infestation rates, and their levels.

Factor	Levels 1	2	3
Treatment	baited stands	check stands	
DBH class (in.)	5 - 6.9	7 - 8.9	9+
HT group (Flathead NF)	cool-wet	cool-dry	
HT group (Kootenai NF)	warm-wet	cool-wet	

In the Flathead NF, the cool-wet (c-w) habitat type group consists of habitat types 620, 621, 624, 625, 660, 662, and 670. The cool-dry (c-d) habitat type group consists of habitat types 640, 663, 690, and 692.

Factors used in the analysis are displayed in table 3.

To obtain a general picture of the distribution of the data, pretreatment infestation (trees per acre) was plotted versus posttreatment infestation (trees per acre). Figure 1 displays infested trees/acre from pre- to postbaiting and pre- to post-flight for check stands for the Flathead NF, and figure 2 displays infested trees/acre from pre- to postbaiting and pre- to postflight for check stands for the Kootenai NF.

There is clearly a significant increase in infestation for both baited and check stands in both forests. Also, the relative lack of check stands is apparent. Observations made in the Flathead NF are substantially larger on the average, in both pre- and posttreatment conditions, than in the Kootenai NF.

Determination of Differences in Infested Trees Per Acre

This analysis attempts to determine the sources of variation in change in infested trees per acre from pre- to posttreatment.

Kootenai NF--Table 4 presents the ANOVA table for the three-way analysis of variance.

Treatment is a statistically significant factor in explaining the variation in change in infested trees per acre from pre- to posttreatment. The average increase in infestation rate for baited stands is 37.1 trees per acre, and 7.8 trees/acre for check stands. DBH is also statistically significant, and the relative differences in infestation rates show that the 7-8.9 inch and 9+ inch DBH classes incur larger changes in infestation rate than the 5-6.9 inch DBH class.

Habitat type group was not found to be a significant factor in explaining changes in infestation rates. The fraction of unexplained variation (50619.93) relative to the total variation (81028.52) is fairly large. This indicates that while treatment and DBH class explain a significant amount of the variation, there is still a large variation unexplained.

Changes in Infestation Rate by DBH Class and Treatment

Table 5 shows specific differences between baited and check stands in change in infested trees per acre within each DBH class. Significance at the 0.05 level was tested by Scheffe's test.

Results of the two sample t-tests show that there are very large differences in infestation rate change associated with treatment in the 7-8.9 inch and 9+ inch DBH classes. Data are insufficient to provide strong evidence of differences between treatments in the 5-6.9 inch DBH class.

Flathead NF--Table 6 presents the ANOVA table for the three-way analysis of variance.

Treatment is a statistically significant factor in explaining variation in the change in infestation rate from pre- to posttreatment. The average change in infestation rate for baited stands is 52.9 trees per acre, and 23.1 trees/acre for check stands. Also, DBH and habitat type are statistically significant. The average change in infestation rate is greater in the cool-dry habitat type group (56.0 trees per acre) compared to the cool-wet habitat type group (26.5 trees per acre). As in the analysis of the Kootenai NF data, there was a substantial amount of unexplained variation.

Changes in Infestation Rate by DBH Class, Habitat Type Group, and Treatment

Table 7 shows specific differences between baited and check stands in change in infested trees per acre within each level of DBH class and habitat type group.

No treatment differences were found to meet the critical t for Scheffe's test. This is attributed to the small degrees of freedom available for the tests, the large amount of unexplained variation, and the conservative nature of Scheffe's test. There is some evidence of a consistent trend relating DBH class and the difference between baited and check stands. Both tables 5 and 7 show the difference between check and baited stands to be smaller in the 5-6.9 inch DBH class than the 7-8.9 inch DBH and 9+ inch DBH classes, except in the c-d habitat type group (Flathead NF), 9+ inch DBH class. This number may be small due to a large portion of the trees in the 9+ inch DBH class having been attacked before baiting, and because the 5-6.9 inch DBH classes are not as susceptible as

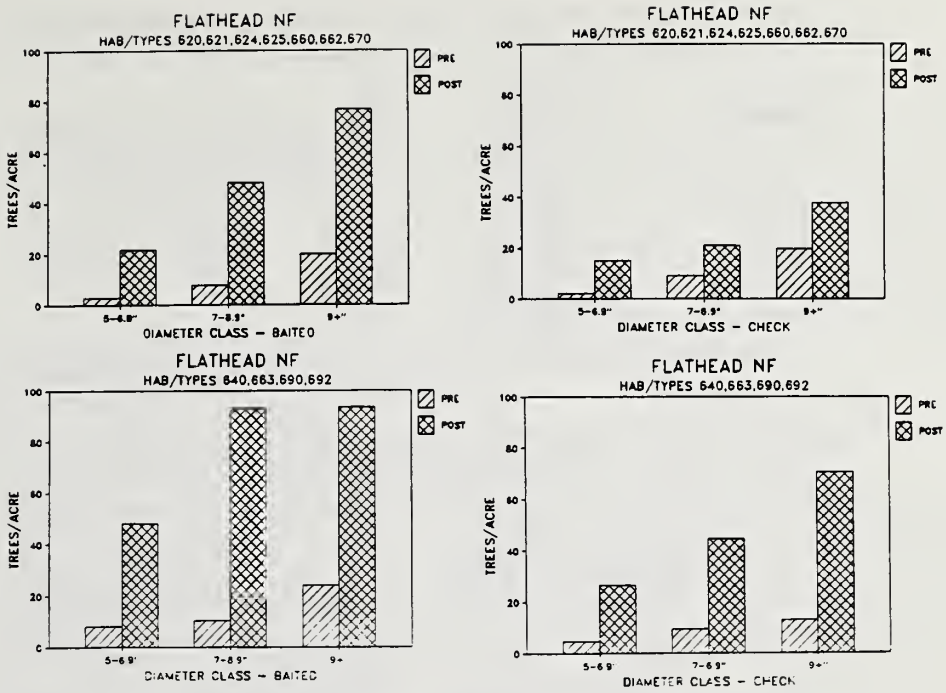

Figure 1--Trees killed per acre by diameter class from pre- to post-baiting, and pre- to postbeetle flight in check stands, Flathead National Forest, Montana, 1985

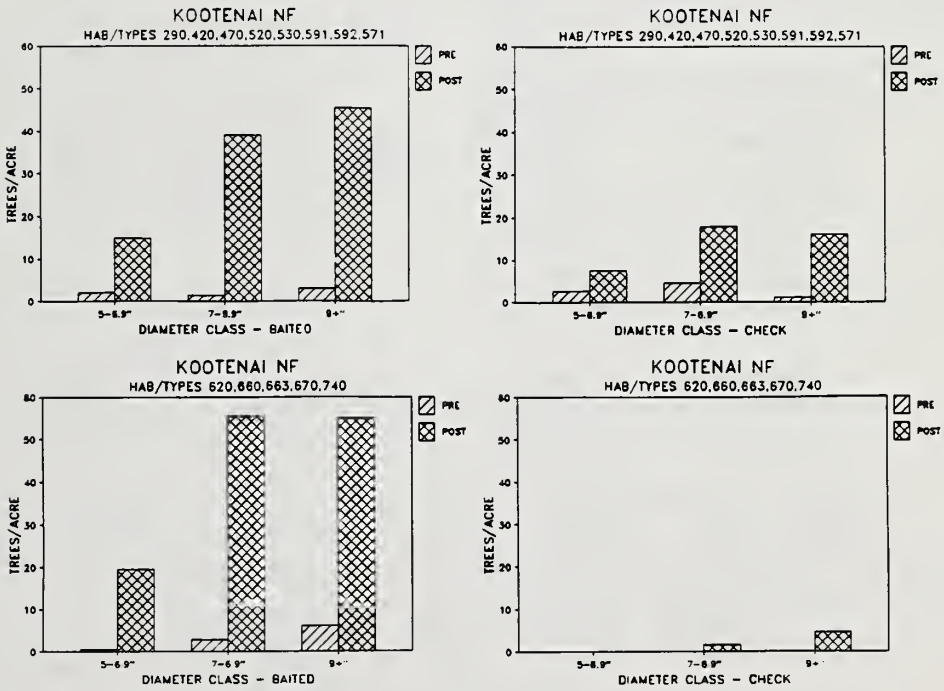

Figure 2--Trees killed per acre by diameter class from pre-to post-baiting, and pre- to postbeetle flight in check stands, Kootenai National Forest, Montana, 1985

Table 4--Analysis of variance table--Kootenai NF, Montana, 1985

Source of Variation	DF	Sums of Squares	Mean Square	F-ratio	P-value
Mean	1	81028.52			
Treatment	1	14811.09	14811.09	28.674	0.000
DBH	2	14902.74	7451.37	14.426	0.000
HT group	1	694.75	694.75	1.345	0.265
Error	98	50619.93	516.53		

Table 5--Average change in infestation rate from pre- to post-treatment within each DBH class on the Kootenai NF, Montana, 1985

DBH class	Infested Trees/Acre Baited	Infested Trees/Acre Checks	Difference	DF	Significance at 0.05 level
5 - 6 in.	16.98	2.37	14.62	31	ns
7 - 8 in.	47.65	8.92	38.72	33	s
9 + in.	46.79	10.97	35.81	33	s

Table 6--Analysis of variance table--Flathead NF, Montana, 1985

Source of Variation	DF	Sums of Squares	Mean Square	F-ratio	P-value
Mean	1	223894.03			
Treatment	1	29548.59	29548.59	24.983	0.000
DBH	2	17793.82	8896.91	7.522	0.001
HT group	1	20431.86	20431.86	17.275	0.000
Error	132	156119.77	1182.72		

Table 7--Average change in pre- to posttreatment infestation rate within each DBH class on the Flathead NF, Montana, 1985

HT group	DBH	Infested Trees/Acre Baited	Infested Trees/Acre Checks	Difference	DF	Significance at 0.05 level
c-w	5 - 6.9 in.	18.69	12.95	5.74	22	ns
c-w	7 - 8.9 in.	40.45	11.99	28.47	22	ns
c-w	9 + in.	56.77	18.16	38.62	22	ns
c-d	5 - 6.9 in.	40.16	21.66	18.55	20	ns
c-d	7 - 8.9 in.	82.66	35.30	47.36	20	ns
c-d	9 + in.	69.33	57.47	11.86	20	ns

larger diameter classes (Cole and Amman 1969; Cole and others 1976; Klein and others 1978; Rasmussen 1972).

Examination of the sample means, displayed in tables 5 and 7, also suggests that DBH class is a major determinant of infestation rate (larger DBH classes suffer larger increases in infestation rates irrespective of treatment).

Conclusions

There is strong evidence that treatment was a factor in determining the change in infested trees per acre, and that the effect of baiting substantially increases the number of infested trees per acre. The fact that differences between specific treatment combinations are not statistically significant can be attributed to the small sample sizes available for these multiple comparison tests, and the amount of unaccounted for variation. There is a clear pattern of larger changes in infested trees per acre in the larger DBH classes. Further, it appears that the effect of baiting is greater in the larger DBH classes. Habitat type group is not a consistent factor in explaining variation in the change in infested trees per acre. However, a larger sample of habitat type groups probably would reduce variation.

Determination of Differences in Build-up Ratio

This analysis attempts to determine sources of variation in the build-up ratio. One drawback to the use of ratios is that a ratio cannot be computed if the denominator of the ratio has a zero value. In these data, there are numerous stands in which the pretreatment infestation rate is 0.0, particularly for the Kootenai NF. These stands are omitted in the following analysis. The distribution of sample observations is displayed in table 8.

The use of build-up ratios instead of the pre- to posttreatment change as a measure of infestation trend has the effect of reducing the relative importance of the stands in which pretreatment infestation was high. For example, consider two stands with pretreatment infestation rates of 10 and 50 trees per acre. Suppose infestation in both stands increases by 50 trees per acre. The change in infestation rates (pre- to posttreatments) is 50.0 in both stands; however, the build-up ratios are 5.0 and 1.0 for each stand, respectively. Consequently, ANOVA using the build-up ratio is more sensitive in detecting factors that affect stands with low initial infestation rates, compared to factors that affect stands with high initial infestation rates.

Kootenai NF--Variation in build-up ratio is shown in table 9. The sensitivity of this analysis is reduced relative to the previous analysis of the Kootenai NF data (using the change in infested trees per acre) because of the reduction of sample size from 103 to 46 observations.

Treatment is the only statistically significant factor. The mean build-up ratio for check stands is 2.6, compared to 14.0 for baited stands. The data are insufficient to conclude that there are substantial differences in the build-up ratio between different DBH classes. This result, contradicting the previous results using the change in infestation rate, may be attributable to sample size differences. The fraction of variation that remains unexplained is large relative to the total variation.

Changes in Build-up Ratio by DBH Class and Treatment

Table 10 shows specific differences between baited and check stands within each DBH class for the Kootenai NF data. Significance tests are not computed since the analysis of variance did not find DBH to have a statistically significant effect upon build-up ratio. The trend of DBH and build-up ratio is not inconsistent with previous results.

Flathead NF--Variation in build-up ratio is described by table 11. Both treatment and habitat type group are statistically significant. The mean build-up ratio for check stands is 4.9, compared to 8.9 for baited stands. DBH was not a significant factor in determining build-up ratio. Unexplained variation is again a substantial fraction of the total variation.

Specific differences between baited and check stands are not identified as statistically significant.

Changes in Build-up Ratio by Habitat Type Group and Treatment

Table 12 shows differences between baited and check stands within each habitat type group for the Flathead NF data.

Changes in Build-up Ratio by DBH Class and Treatment

Table 13 displays the trends in build-up ratio by DBH class for the Flathead NF.

Tables 10 and 13 show that the 7-8.9 inch DBH class is observed to have the largest difference in build-up ratio among the three diameter classes.

Table 8--Number of valid observations based upon build-up ratio

Flathead NF		Baited Stands DBH Class			Check Stands DBH Class		
		5 - 6.9	7 - 8.9	9 +	5 - 6.9	7 - 8.9	9 +
HT group	c - w	7	9	12	3	9	10
	c - d	9	14	15	4	7	8

Kootenai NF		Baited Stands DBH Class			Check Stands DBH Class		
		5 - 6.9	7 - 8.9	9 +	5 - 6.9	7 - 8.9	9 +
HT group	w - w	3	4	6	1	3	3
	c - w	2	10	15	0	0	0

Table 9--Analysis of variance table for build-up ratio--Kootenai NF, Montana, 1985

Source of Variation	DF	Sums of Squares	Mean Square	F-ratio	P-value
Mean	1	7513.74			
Treatment	1	788.40	788.40	5.292	0.026
DBH	2	591.50	295.75	1.985	0.150
HT group	1	26.23	26.23	0.176	0.677
Error	41	6107.61	148.97		

Table 10--Mean build-up ratio for each DBH class on the Kootenai NF, Montana, 1985

DBH class	Baited Stands Trees/Acre	Check Stands Trees/Acre	Difference
5 - 6 in.	4.34	0.54	3.80
7 - 8 in.	18.40	1.27	17.13
9 + in.	13.52	6.54	6.97

Table 11--Analysis of variance table for build-up ratio--Flathead NF, Montana, 1985

Source of Variation	DF	Sums of Squares	Mean Square	F-ratio	P-value
Mean	1	7028.40			
Treatment	1	347.62	347.62	5.602	0.020
DBH	2	175.63	87.82	1.415	0.248
HT group	1	299.73	299.73	4.830	0.030
Error	100	6205.37	62.05		

Table 12--Differences between treatments in the mean build-up ratio within habitat type groups--Flathead NF, Montana, 1985

HT group	Baited Stands Trees/Acre	Check Stands Trees/Acre	Difference	DF	Significance at 0.05 level
c-w	7.32	2.86	4.46	57	ns
c-d	10.00	7.40	2.60	54	ns

Table 13--Mean build-up ratio for each DBH class on the Flathead NF, Montana, 1985

DBH class	Baited Stands Trees/Acre	Check Stands Trees/Acre	Difference
5 - 6.9 in.	18.77	5.57	3.20
7 - 8.9 in.	11.84	4.29	7.55
9 + in.	6.38	5.29	1.09

Conclusions

The analysis shows baiting substantially increased the number of infested trees per acre. Differences between specific treatment combinations were not found to be statistically significant using Scheffe's test. Using the build-up ratio as a response variable apparently has the effect of reducing the influence of stands with large pretreatment infestation rates since these stands cannot experience very large build-up rates. It is suggested that high pretreatment infestation rates have reduced the difference in build-up ratios between the 7-8.9 inch and 9+ inch DBH classes, and the 5-6.9 inch DBH class.

Effect of LPP in the 5-6.9 inch DBH Class

This analysis attempts to determine whether the effectiveness of baiting is affected by the percentage of LPP in the 5-6.9 inch DBH class. Field observations suggest that stand composition is a major factor in determining the effectiveness of baiting. Specifically, the percentage of lodgepole pine in the 5-6.9 inch DBH class is thought to affect infestation and response to baiting. The objective of this analysis is to determine if the percentage of lodgepole pine in the 5-6.9 inch DBH class influences the effectiveness of baits.

In this analysis, the percent LPP in the 5-6.9 inch DBH class is compared to the percent of total LPP mortality (all DBH classes). All stands are used in this analysis instead of restricting the analysis to the major habitat type groups since the intent is not to determine the effect of specific factors, but to determine a general trend applicable to all stands in a National Forest.

Figures 3 and 4 are plots of percent LPP in the 5-6.9 inch DBH class versus percent mortality. A regression equation is graphed on each figure, summarizing the trend in baited and check stands in the Flathead NF, but only baited stands in the Kootenai NF. The regression equations are computed by regressing percent LPP mortality on percent LPP in the 5-6.9 inch DBH class. The appendix provides the statistics for the regression equations.

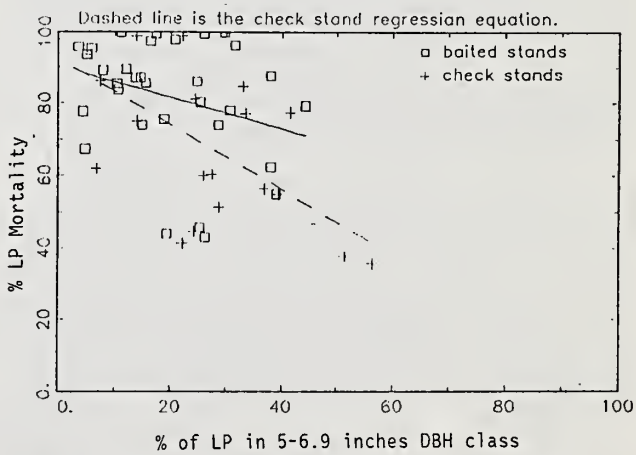

Figure 3--Plot of percent of LP in the 5-6.9 inch DBH class versus percent LP mortality observed at remeasurement, and the graph of the regression equations. Flathead National Forest, Montana, 1985

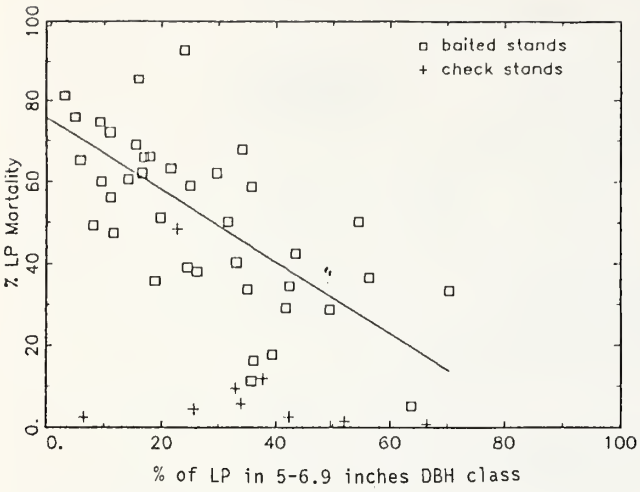

Figure 4--Plot of percent of LP in the 5-6.9 inch DBH class versus percent of LP mortality observed at remeasurement, and the graph of the regression using baited stands. Kootenai National Forest, Montana, 1985

Results--Flathead NF

Figure 3 shows the plotted data and the fitted regression equation for the Flathead NF. The range of the data is unfortunately small as there were no baited stands with more than 44 percent of the pretreatment LPP in the 5-6.9 inch DBH class. Data show that stands with small percent LPP in the 5-6.9 inch DBH class suffer higher mortality rates. The mortality rate declines as the percent LPP in the 5-6.9 inch DBH class increases. The mortality rate is still quite high at the largest observed percent LPP in the 5-6.9 inch DBH class. The regression analysis in the Appendix shows that percent LPP in the 5-6.9 inch DBH class is not a statistically significant predictor of percent LPP mortality since the t statistic testing the significance of the independent variable is 1.663 and the associated p value is 0.107.

Percent LPP in the 5-6.9 inch DBH class is a statistically significant (p value = 0.001, Table 3 Appendix) predictor of LPP mortality in the check stands. However, the relationship is not strong because of the low r2 (0.435). For check stands, as percent LPP in the 5-6.9 inch DBH class increased, average DBH declines, thus decreasing overall stand susceptibility (Cole and Amman 1969; Cole and others 1976; Klein and others 1978).

Results--Kootenai NF

Figure 4 shows the plotted data and the fitted regression equation for the Kootenai NF. The range of susceptible LPP in the 5-6.9 inch DBH class is 0 to 70 percent; a substantial difference compared to data from the Flathead NF. Data show a clear tendency for the mortality rate to decline as the percentage of the LPP in the 5-6.9 inch DBH class increases. The regression analysis in the Appendix shows that percent LPP in the 5-6.9 inch DBH class is a statistically significant predictor of percent LPP mortality since the t statistic testing the significance of the independent variable is 16.109 and the associated p value is 0.000.

Conclusions

Data from baited stands in the Kootenai NF show percent mortality due to baiting does depend upon percent LPP in the 5-6.9 inch DBH class, and the effect is to retard posttreatment mortality. The data are insufficient to support this conclusion for the Flathead NF. A possible reason is that the range of the data is limited and beetle infestation in the vicinity of Flathead NF stands was so great that the beetles attacked the majority of trees larger than 5 inches DBH prior to baiting. Data from baited stands in the Kootenai NF and check stands in the Flathead NF suggest a strong preference for larger DBH classes.

Figure 4 can be used to establish a maximum percent LPP in the 5-6.9 inch DBH class such that baiting is effective. For example, to obtain at least 50 percent mortality following baiting requires that no more than 29 percent of the LPP is in the 5-6.9 inch DBH class. On the other hand, if 60 percent of the LPP is in the 5-6.9 inch DBH class, then only 23 percent mortality is expected after baiting. Caution ought to be exercised in the use of the regression equations in figures 3 and 4 since LPP diameter distribution in stands of other forests are likely to be different.

One can rest assured that semiochemical baiting and sanitation logging will not remove all infested trees in localized areas. Many instances can be brought to mind that following cutting and removing infested trees, one later finds individual attacked trees or small patches of infested trees around the periphery of cut blocks. Whether these beetles come from brood trees not included in the cut block or from a population remaining in stumps following cutting is not really important. What does matter is that these newly infested trees or groups of trees do represent the potential for building beetle populations in the surrounding stands and should be dealt with if the stand is in a beetle management area. Where infested trees are detected late in the year following cutting, baits can be placed around the block during spring or early summer the following year. Baits should be attached to large-diameter trees, 25 meters in from the edge, and if the cut unit boundary is more than a spot, baits can be spaced at 100-meter intervals around the edge. Baited trees will serve as aggregation centers for the residual beetle population; following flight, newly attacked trees can be harvested with small sales, felled and burned, or treated with chemicals (Borden and others 1983b; Hall 1985).

Diversion Baiting

Baiting to divert beetles away from leave strips (riparian areas or other high-value stands) may be an additional option (Borden and Lacey 1985); however, this strategy has not been tested to our knowledge. It is possible to use it in conjunction with antiaggregation pheromones (verbenone) and possibly repellents, but field testing of this strategy is needed prior to it being recommended for operational use. Baiting stands scheduled for harvest adjacent to or near stands protected by use of ground or aerially applied antiaggregates or repellents may prove to be a useful tool.

It must be emphasized that semiochemicals will not control beetle populations. They may in fact aggravate the problem. Aggregation pheromones manipulate beetle populations by restricting dispersal, or may possibly enhance it in the case of antiaggregates or repellents. If not used in conjunction with harvesting or single-tree treatment, the infestation will probably expand more than if pheromones were not used. Where semiochemical tree baits are used, beetles normally lost during dispersal may have a better chance of finding suitable host trees, thereby increasing the number of trees successfully attacked over the number of trees attacked had baits not been used (Hall 1985). Careful selection and baiting of larger diameter trees, which the beetle naturally prefers, will increase effectiveness of baiting and probability of mass attack. Baits should be placed in the field well ahead of any beetle flight that might result in establishment of natural competing attraction centers. It is unlikely that any semiochemical tree bait will compete or outcompete a natural attractant.

Semiochemical tree baits are past the stage of just being a scientific curiosity. However, it should be kept in mind that pheromones, whether attractants, antiaggregates, or repellents, must be used in coordination with other appropriate management strategies.

We are all involved in management programs to reduce or avoid losses to bark beetles. We should employ those strategies that reduce the long-term impacts of bark beetles through harvesting or other short-term methods. Semiochemicals should be incorporated into our "bag of tricks" to help meet these management objectives.

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Appendix. Regression Equations Shown in Figures 3 and 4.

A regression equation is fit to the data in figure 3 to summarize the expected percent mortality given the percent susceptible LP in the 5-6 inch DBH class. The regression model specifies that the dependent variable is percent mortality, and the independent variable is percent susceptible LPP in the 5-6 inch DBH class. The regression statistics are displayed in table 14.

The same regression equation is fit to the data in figure 4 from the Kootenai NF. The regression statistics are displayed in table 15.

Table 14--Statistics for the regression of percent LPP mortality on percent susceptible LPP in the 5-6 inch DBH class using baited stands on the Flathead National Forest, Montana

Observations:	32	Degrees of freedom:	30
R-squared :	0.084		
Residual SS :	7830.292	Std error of est :	16.156
Total SS :	8552.402	F(2 ,30)=2.7666 P-value=0.08	

Variable	Coeff.	Std. Error	t-Stat	P-Value
CONSTANT	90.154	5.838	15.441	0.000
% LPP 5-6	-0.428	0.257	-1.6633	0.107

Table 15--Statistics for the regression of percent LPP mortality on percent susceptible LPP in the 5-6 inch DBH class using baited stands on the Kootenai National Forest, Montana

Observations:	40	Degrees of freedom:	38
R-squared :	0.479		
Residual SS :	9664.144	Std error of est :	15.947
Total SS :	18562.058	F(2 ,38)=34.9871 P-value=0.00	

Variable	Coeff.	Std. Error	t-Stat	P-Value
CONSTANT	75.653	4.696	16.109	0.000
% LP 5-6	-0.882	0.149	-5.915	0.000

Table 16--Statistics for the regression of percent LPP mortality on percent LPP in the 5-6.9 inch DBH class using check stands on the Flathead National Forest, Montana

Observations:	21	Degrees of freedom:	19
R-squared :	0.435		
Residual SS :	5239.637	Std error of est :	16.606
Total SS :	9266.386	F(2, 19)=14.6081 P-value=0.00	

Variable	Coeff.	Std. Error	t-Stat	P-Value
CONSTANT	92.204	6.811	13.538	0.000
% LP 5-6	-0.898	0.236	-3.821	0.001

THE USE OF MOUNTAIN PINE BEETLE AGGREGATION SEMIO-CHEMICALS IN BRITISH COLUMBIA

P.M. Hall

ABSTRACT: The Province of British Columbia has been experiencing outbreaks of mountain pine beetle since the mid-1970's. In response, an aggressive management program was initiated in 1984 to reduce the rate of loss, protect high value stands, and allow an orderly, co-ordinated approach to lodgepole pine/mountain pine beetle management. This program has included extensive use of aggregating semio-chemical baits as an integral part of many activities. These baits have proven effective in manipulating localized populations of beetles, thereby enhancing the effectiveness of management efforts.

INTRODUCTION:

Now and for the foreseeable future, the forest industry is the number one economic driving force in British Columbia. In 1985, forest-based industries directly employed about 7 per cent of British Columbia's work force and formed the economic base for many communities on the coast and in the interior of the Province. The value of shipments from British Columbia wood industries was about $5.1 billion that year, and was an additional $3.4 billion from paper and allied industries. These accounted for about 45 per cent of the total value of shipments from British Columbia's manufacturing industries.

It is the mandate of the government to support this industry and ensure a continuing, strong economy. Large scale depletions of merchantable timber can cause significant disruptions to the industry and may lead to closures of specific processing facilities in affected areas. The government, through the policies and activities of the Ministry of Forests and Lands, has a responsibility to deal with potential depletions as occur in large outbreaks of bark beetles. Damage and losses must be minimized if at all possible.

In the interior of British Columbia, the forest industry is heavily dependent on a diet of lodgepole pine, Pinus contorta, (Anon, 1984 and 1986). The volume of pine harvested in the province in 1985/86 was 18.2 million m^3, second only to the volume of spruce harvested. The area occupied by mature pine types represents about 21 per cent (8.1 million hectares) of the total Forest Land Base in Timber Supply Areas (TSA's); the volume of mature pine types represents about 24 per cent of all mature volume in TSA's and 20 per cent of all volume of mature and immature combined. TSA's represent approximately 92% of the forest land base of the Province; the remainder is managed under other tenure agreements. From these figures it is obvious that British Columbia is "blessed" with vast amounts of pine with an age-class imbalance biased towards mature types. In many respects, we have an infestation of lodgepole pine highly susceptible to mountain pine beetle, Dendroctonus ponderosae. These statistics are presented to emphasize the need to put management of mountain pine beetle in the context of general forest management objectives. Catastrophes such as widespread mountain pine beetle outbreaks affect many aspects of management.

Mountain pine beetle arrived on this stage most recently in the early 1970's. By the mid-1970's infestations were noted at many locations throughout the interior of the Province. Although salvage logging was directed at infested stands in most of these areas, little was done to try to reduce the active beetle populations.

Throughout the 1970's, mountain pine beetle expanded, both in the size of particular infestations and in the number of infestations. It was projected that the eventual size of the outbreak in the Province would be limited primarily by the availability of host.

In 1981, active infestations covered over 158,000 ha (Fiddick and VanSickle, 1982) and had killed a volume estimated at 6.6 million m^3 in the preceding year alone. By 1983, infestations covered over 460,000 ha and in 1984 had reached over 480,000 ha (Wood and others, 1985). Total cumulative losses to that time were estimated as over 50 million m^3 of pine.

The impacts of these outbreaks affected management plans at all levels. Large areas of gray, dead stands of pine existed in many locations in the Province. Many of these stands had previously been included in the net operable forest land base and therefore the volumes were

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included in determinations of cut levels. These gray stands were declining in value rapidly and affected Regions were anticipating reductions to annual allowable cuts (AAC) at least in the short-term (20 years) due to age class gaps in the timber profile. Many accommodations had to be made: development plans and access construction schedules were altered; AAC's were reviewed and modified; plans and costs of rehabilitation were developed; and, the short and long-term probabilities of fire were considered when developing protection plans.

Some sort of program was required to be put in place. Rather than address a specific outbreak, a program was developed that would allow action to be taken in all Regions against suitable infestations (Hall, 1985; McMullen and others, 1986).

This bark beetle program was not intended to "control" the outbreaks; rather, activities were directed towards reducing the rate of loss, limiting the expansion of target infestations and allowing time to co-ordinate management plans to deal with outbreaks. Activities funded under the program were:

- accelerated access development;
- intensive aerial and ground surveys (including extensive use of 1:10,000 colour aerial photography);
- prioritized harvesting; and,
- concentrated single tree treatment programs in spot locations and on the leading edge of major outbreaks.

The use of semio-chemicals, in particular aggregation semio-chemicals, was integral to many of these activities. It was viewed that many of the activities and specific treatments directed towards mountain pine beetle would not be acceptably effective in reducing spread unless there was the ability to manipulate beetle populations fairly consistently. Semio-chemicals offered this opportunity.

Development of Baits

The Forest Service had limited experience in the use of this tool, but had been interested in and supported the development and refinement of these chemicals since the mid 1970's. At the inception of the bark beetle program in 1984, the position was taken that sufficient experimentation and trials had been done in British Columbia to establish their efficacy in certain use patterns (Borden and others, 1983A and 1983B; Conn and others, 1983). These previous trials were used to justify the extensive use of semio-chemicals in operational programs. It was also decided that their use or effectiveness would be monitored throughout the program and that their overall benefit to cost efficiency would be assessed in some detail during the overall program evaluation. This detailed evaluation is being undertaken during the 1988/89 fiscal year.

It should be mentioned here that the semio-chemical mix, currently in use, is not a perfect match to the naturally produced aggregation complex. However, this bait mix is consistent in inducing mass attack on baited trees. Further, the effective distance (50 m) between baited trees on a grid placement system appears to be effective in reducing or preventing escapes from baited areas.

Therefore, it was decided that the bait was effective enough in manipulating beetle populations that it could be used in certain well-defined use patterns to enhance beetle management efforts.

Rationale for the Use of MPB Semio-Chemicals

It is relevant at this time to go back a bit to review a previous bark beetle program in British Columbia during the early 1980's. In 1981, with both mountain pine beetle and spruce beetle, Dendroctonus rufipennis, on the increase in the Province, a two-year, $11.4 million program was implemented in an effort to establish some level of management. This program was terminated after one year due to the recession and fiscal restraint policies; however, some observations from this program pertain to the use of semio-chemicals.

Activities funded at that time were essentially the same as in the current program. One of the major differences, and possibly a major deficiency of the program, was the lack of use, or availability, of an operationally acceptable aggregation semio-chemical. Dispersal of beetles from population centres could not be predicted or managed with any precision. If infestations were not treated prior to the next beetle emergence period, extensive and expensive ground probing was required to locate new population centres potentially dispersed over larger areas.

In 1984, with a useable bait, the probability of success of a management program increased substantially. Manipulation of beetle populations enhances the effectiveness of beetle management activities. For instance, sanitation harvesting (as opposed to salvage) can be made much more effective in removing beetles from a stand, thereby reducing the risk of increasing infestation in neighbouring, susceptible stands. Similarly, in single tree treatment areas, beetles in those spots not dealt with prior to beetle flight, and residual beetles remaining in areas subsequent to treatment, can be arrested at pre-selected baited trees. Such restrictions on dispersal to predetermined areas greatly reduces the survey effort involved in locating population centres and reduces the size of treatment areas or cutblocks while addressing a larger proportion of a resident beetle population. Further, predetermining sites of newly attacked trees allows substantial increases in the use of MSMA (monosodium methanarsonate) - a treatment both faster and cheaper than conventional fall and burn efforts.

The use of baits should be integrated with hazard and risk assessments. Hazard ratings attempt to measure the susceptibility of a stand

should it become infested, while risk estimates the probability of a stand becoming infested. In effect, risk rates the beetle's "pressure" in a particular area. In a manner of speaking, semio-chemicals allow us to manipulate risk while harvesting strategies manipulate hazard.

A general principle of semio-chemical use should be emphasized. These baits are tools to be integrated with all other available tactics to achieve rather specific objectives. They are not a treatment unto themselves as, when used alone, they do nothing to reduce beetle population levels. In fact, the converse may be the case. Without subsequent follow-up, beetle populations may increase, and damage in terms of volume killed may increase as well. Semio-chemical baits, by definition, restrict dispersal and therefore reduce the proportion of beetles which would die through the dispersal process. Greater numbers of beetles will find suitable host material resulting in larger subsequent generations and attack levels. More trees may be attacked within a baited stand than may otherwise be the case. Further, as baiting criteria stress selection of the largest trees in an area, brood production may be greater per tree and the diameter distribution of attacked stems in a stand may be higher than normal. Therefore, the need for follow-up action, subsequent to the application of baits, must be clearly acknowledged at the inception of any management program.

Use of MPB Semio-chemicals in British Columbia

In British Columbia, semio-chemicals are being used extensively for two primary purposes:

1) for containment of beetle populations within proposed sanitation cut blocks; and,
2) as an aid in treatment of small infestation patches using single tree treatments (Heath, 1986B).

These uses do not require the "perfect" bait; rather, they depend upon the bait's consistency in inducing attack and resultant natural centres of attraction.

Purchase of baits under the bark program has been extensive in the past few years (Table 1). This level of use is expected to continue for the duration of the bark beetle program.

Table 1--Levels of Bait Purchases in the British Columbia Bark Beetle Program

Year	Number of baits Purchased[1]
1984/85	32,250
1985/86	63,400
1986/87	53,685
1987/88	44,500
Total	196,835

[1]Forest Service purchases only.

Expenditures on semio-chemicals have been significant. Purchase costs have varied somewhat from year to year due to pricing changes and bulk purchase discounts; however, an average cost per bait of $5.75 per year is reasonable. Other costs must also be considered.

Placement and overhead costs must be considered, especially in containment baiting. These have been roughly estimated as about $5.00 per bait. This cost includes placement in field, planning, storage/shipment, and some monitoring and assessment. This may be considered high as baits are often placed during other stand entries - still, it is a hidden cost. The total cost of using semio-chemicals is therefore about $10 - $11 per bait, especially in containment programs.

Containment baiting

Sanitation harvesting (i.e., logging and processing of stands with beetle brood producing trees) is the most efficient method of reducing beetle populations. Not only is a beetle population removed from an area, but values are received for the timber products.

If a block cannot be scheduled for cutting prior to the beetle emergence and flight period, significant emigration of the emerging beetles out of the block can often be expected. Peripheral stands will be attacked, or widely dispersing beetles may initiate additional infestation centers some distance away. The maximum effect of the sanitation cut will be lost: more trees will be killed; beetles may establish themselves in inaccessible areas; and, extensive and expensive surveys will have to be conducted to relocate and treat the escaped population. At this point, treatment of some stands may no longer be feasible.

This emigration of the target population can be reduced, or even prevented through the use of baits. Live, apparently susceptible trees within the block can be baited with semio-chemicals prior to the beetle flight period. When beetles emerge and begin searching for and attacking new hosts, the previously baited trees are usually the first attacked. Once baited trees are attacked, the natural attractant bloom produced by the beetles will further concentrate the population. Harvesting after the beetle flight period will therefore remove the resident beetle population (except those individuals left in stumps) and any beetles immigrating into the block as a result of the semio-chemical treatment. The use of aggregation baits will enhance the efficiency of sanitation logging and allow the removal and disposal of a greater proportion of the resident beetle population in an area.

British Columbia has been using two methods of baiting for sanitation logging. In smaller blocks, baits are put on trees at 50 metre grid intervals starting 25 metres in from the block

boundaries. Beetles emerging from brood trees should, therefore, be no further away from a baited tree than about 35 m.

The second method entails baiting trees 50 metres apart in two lines also 50 metres apart around the inside of the boundary of the proposed block. Areas where brood trees are concentrated within the block are baited on a 50 metre grid. Therefore, the bulk of the emerging beetles will find themselves in close proximity to baited trees and the remaining population within the treated area should either naturally find host trees within the block or be arrested at the periphery.

Use of baits is restricted by scheduling. Ground and aerial surveys are used extensively in late summer and winter to establish harvesting priorities based on access, merchantibility and infestation intensity. Blocks are identified, delineated, and cutting permits issued within a short time. Only blocks identified as having beetles, but that cannot be scheduled for harvest prior to beetle emergence are suitable for containment baiting.

Harvesting of these baited blocks is expected to occur during the year following baiting. Areas may be baited for successive years to hold beetle populations in place, but this is not done as a matter of course in British Columbia. There must be some plan for removal within a short period of time.

Evaluations of the effectiveness of containment baiting have not been extensive. As mentioned earlier, the decision was made at the outset of the program that efficacy had been shown and that monitoring and post- program assessments would occur on a continuing basis and at the end of the five year program.

The few formal evaluations of block baiting that have been made have supported the continued use of semio-chemicals for containment baiting(Gray and Borden, 1988; Heath, 1986A). A caution, however, is that a significant population of beetles should be present to justify treatment. The effectiveness of baits needs to be assessed further in regard to sparse or declining populations of mountain pine beetle.

Bait use in single tree treatment

The other major use of aggregation pheromones now employed in British Columbia is in augmenting single tree treatment projects such as fell and burn, or injection of MSMA. Single tree treatment projects are implemented to sanitize lightly infested stands, remove small patches in inaccessible areas or that cannot be removed through small volume timber sales, and to mop-up around the periphery of sanitation logging. This has been a large part of the current program (Table 2).

One of the most labour intensive and time consuming tasks in these types of projects involves finding and marking currently attacked trees containing viable brood. Semio-chemicals have greatly reduced this component and therefore make the work more efficient.

Table 2--Levels of Single Tree Treatments[1] in the British Columbia Bark Beetle Program

Year	Number of trees Treated
1984/85	40,231
1985/86	43,582
1986/87	57,619
Total	141,432

[1] Includes fall and burn, MSMA, and other methods.

It can be assumed (or assured) that sanitation logging will not remove all the beetles in a localized area. There have been many instances of cutting out infestations and then later finding small infested patches of trees around the periphery of blocks. Whether these beetles came from brood trees not included in the cut block or whether they represent the population remaining in stumps after cutting before the flight period does not really matter. These new patches do represent the potential for further damage to the surrounding stands and should be dealt with promptly if the stand is within a beetle control area.

Baits can be placed around the cut blocks during the final phases of logging. Blocks logged in the late summer or in the fall should be revisited early the following summer and baited. Baited trees in the stand surrounding a new cut block should be located about 25 m in from the edge and be spaced at 100 m intervals in the remaining susceptible type around the edge of the block. These baited trees will serve as aggregation foci and the residual beetle population in the area should be clumped around these predetermined spots. After the beetle flight period, attacked trees may be harvested with small timber sales, felled and burned, or, if treatment is possible within three weeks of attack, they may be treated with a hack and squirt application of MSMA.

Single tree treatment to sanitize stands not scheduled for harvest within a few years, or in remote areas where high value stands are threatened, is practiced in British Columbia to buy time. Again, the greatest expense is locating and marking the trees for disposal which may often require helicopter access and multiple entries for survey and location and again for treatment. The chances are that some trees will be missed and therefore not treated or that there will be some beetle production from remaining stumps or incompletely treated trees. Thus, further tree mortality should be expected in years subsequent to the initial treatment and the tactical use of semio-chemicals will make further treatments more efficient as the search time required will be substantially less.

When single tree treatments are done from late winter up to the beetle flight period, a few trees should be baited around the spot just as the site is left. These trees should serve as foci for aggregating the residual population and therefore additional trees attacked can easily be found and treated. Potential treatment sites can be identified and baited throughout the summer. The great reduction in survey time and efficiencies in pre-determining potential treatment sites more than compensates for the costs of bait placement.

MSMA offers an opportunity to treat infested trees quickly, easily, and cheaply. Estimates of costs for treatment by fall and burn range from $20 per tree in areas with exceptional access to over $100 per tree in areas requiring helicopter access. Province-wide, a rough average would be about $50 per tree. In contrast, treatment costs for MSMA are less than $10 per tree. The greatest constraint on the use of MSMA is the requirement to treat a tree within three weeks of the time of beetle attack (Dyer and Hall, 1979). After this, treatment is ineffective due to blocked translocation in the tree through colonization by blue stain fungi or because of larval feeding. Because of this narrow window for treatment, it is crucial to find newly infested trees quickly. Baiting trees serves to pre-select attacked trees and has enabled a rather large scale use of MSMA in British Columbia. For example, in 1987, approximately 12,000 trees were treated successfully with MSMA. Baiting trees also allows greater precision in scheduling activities and in defining treatment areas, necessary for obtaining pesticide use permits.

All assessments done to date indicate that baits are effective in limiting dispersal. It is our perception that baiting has made single tree treatment projects viable as a management tactic. Thoroughness and follow-up for a period of years, however, are prerequisites to such efforts.

Program Evaluation:

Quantitative and qualitative evaluations of the impact of semio-chemical use will continue. However, it is necessary to evaluate these chemicals within the context of the overall management program. In British Columbia, as stated earlier, the objectives of the current bark beetle program are to slow the rate of expansion of infestations, and to protect high value stands. Access and harvesting schedules are also modified to facilitate salvage, sanitation, and pre-emptive harvesting. Semio-chemicals are but one tool to be employed in a co-ordinated, integrated fashion with other activities. It will be necessary, therefore, to determine the effectiveness of the program as a whole and work backwards to show the contribution of baiting.

The greatest difficulty in determining the benefits of semio-chemical use, or any other aspect of a beetle management program, lies in defining what would have occurred without intervention. The initial justification for the program was based on continued, expanding attack throughout the high hazard pine at risk. This may have been overstated, as it is likely that:

- all susceptible pine would not have been attacked;
- in most cases stands that were attacked would not have been 100% destroyed; and,
- many of the attacked stands would have been harvested in any event and, therefore, potential actual loss would not be equal to total infested volume.

At any rate, losses were projected to be potentially large at least in the short-term (i.e. - 20 years). Long-term losses, or AAC reductions, were not anticipated. The main effect of the beetle outbreak was expected to be the removal of much of the mature age class component in specific affected areas. This would lead to timber shortages and potential mill closures while decimated stands were rehabilitated or regenerated naturally.

To estimate what would have happened without intervention, a number of techniques will be used:

1) in areas where consecutive annual 1:10,000 colour aerial photography has been taken, treated and untreated areas will be evaluated for rate of infestation increase, total area of infestation, and infestation dispersion;

2) detailed aerial and ground survey data from selected areas will be collated and tracked in relation to management activities to show progress. In effect, the intent is to indicate how effective the program was by detailing specific case studies and then extrapolating; and,

3) perhaps the greatest tool will be the use of various modelling efforts. Currently, a series of models which examine various aspects of mountain pine beetle/lodgepole pine interactions are being developed jointly by the Forest Service and the Canadian Forestry Service. When joined, these models will illustrate beetle dynamics in various pine types and the beetle's impact on timber supply. Different treatment scenarios can then be evaluated.

In terms of semio-chemical use alone, simulations should show the impact they have on limiting damage over the run of the model. It should be pointed out that one of the assumptions of the model is that semio-chemicals restrict dispersal; therefore, only their efficacy in reducing impacts through use in harvesting and single tree treatment programs can be evaluated.

Summary

Only observation and experimentation can confirm that existing baits perform as expected. In operational programs, however, some questions must be asked and answered:

1) Do semio-chemicals work and how well? Based on experimentation, field observation, and limited formal assessments, the existing baits are effective in arresting beetle flight. Baited trees are consistently attacked first in stands and serve as foci for the production of the natural attractant bloom.

   Further research is likely to refine the component mix of the bait to more closely resemble natural attraction. This will likely lead to improvements in the bait's effectiveness and possibly make the use of traps more appealing. However, further refinements would likely also lead to substantial cost increases. Use strategies employed currently take good advantage of the bait's effectiveness; even better baits may not justify possible cost increases. Traps would likely continue to have low useage, even if greatly more effective. Attractant semio-chemicals appear to have the greatest utility when integrated into harvesting or other similar conventional forestry practices.

2) Are the objectives of their use strategies realistic?

   Baits are used only to initiate attraction centres and restrict emigration of beetles out of target areas. As such, they are intended to manipulate localized populations in rather limited ways. These tools are not recommended for long range manipulations or for bringing populations in over large areas. Their use is to reduce the risk of beetle attack in adjacent stands.

   There is no doubt or argument that the most effective way of reducing losses to bark beetles over the long-term lies in manipulating the extent and type of the forest. However, both short and long-term strategies must be maintained.

   We have made the decision to deal directly with bark beetles rather than relying solely on stand manipulations to reduce long-term losses. Therefore, tools that allow us to manipulate beetles (i.e. risk) must be incorporated into management programs. As stated above, the effectiveness of the entire program is enhanced with the use of semio-chemicals.

3) Costs and gains?

   Costs of baits, even with a bulk purchase, have risen above the $6 per bait level. Therefore, in bait costs alone, restricting beetle dispersal from single tree treatment sites is about $25 per site and bait only costs for containment harvesting is about $25 per hectare - double this cost if overhead and placement costs are included.

   It is difficult to precisely quantify the gains versus these costs. However, we are now able to reduce survey/probe costs per site and increase the number of sites visited, treated, or harvested. Cut block sizes have been reduced as a result of baiting and, possibly most importantly, in many cases spots have not expanded beyond treatment or harvest capabilities. It is felt that the overall evaluation of the beetle program will reflect the value of semio-chemical use. Manipulation of localized beetle populations is integral to the efficiency of direct control.

4) Best circumstances? Worst?

   Application of semio-chemicals appears to work to greatest advantage in light to moderately infested stands where sufficient trees exist for baiting or in spot infestations where the intent is to arrest the dispersal of residual beetle populations. Baiting in the midst of extensive, heavy infestations may not be of great benefit as population pressure may overwhelm the baits in treated stands, and because attacks by surrounding populations would likely counter-balance any reductions resulting from containment baiting.

   There is some concern regarding use of aggregation baits in low level or endemic situations. Concentrating such populations may actually trigger an aggressive outbreak. Left alone, such populations may disperse and cause no problem. Although difficult to study, this aspect should be researched further. The concept of routinely aggregating and removing beetles as a matter of course during normal harvesting practices is appealing; it would maintain low risk and may pre-empt future outbreaks.

5) Risks associated?

   The greatest risk in use of baits lies in the necessity of ensuring follow-up action. The commitment and ability to ensure subsequent removal of infested material is key. This re-emphasizes the point that the use of baits or any other tool must be fully integrated into the overall forest management program.

Future use of semio chemicals will be dependent on the results of the current program evaluation and on additional research. Additional research should include examination of the effect of semio-chemical use on endemic populations and on the effect of beetle population vigour on the response to various bait formulations or placement strategies. Refinements to the existing formulation may also be of benefit as would research into the practicability of using repellants or anti-aggregation semio-chemicals.

The bark beetle program in British Columbia was designed to accomplish limited short-term objectives and indications are that the strategy was appropriate. Numerous examples exist in the Province where infestations have been brought under some measure of control when compared with other areas where no action was taken. The ability to manipulate beetle populations by limiting dispersal over large areas has played a significant role in this program.

Future management of pine will likely require an ability to deal with mountain pine beetle; long-term prescriptions cannot be totally effective. Semio-chemicals and other tools will be required and will be used to deal with specific circumstances.

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MOUNTAIN PINE BEETLE AGGREGATION SEMIOCHEMICAL USE IN ALBERTA AND SASKATCHEWAN, 1983-1987

H. F. Cerezke

ABSTRACT: A recent outbreak (1976-1986) of the mountain pine beetle, Dendroctonus ponderosae Hopk. in southwestern Alberta and Saskatchewan prompted control programs to be initiated in 1980-82 within three forested areas and involving three provincial agencies. The programs incorporated newly developed mountain pine beetle semiochemical tree baits during 1983 to 1987 to assist in the control strategies. A variety of information collected mostly in 1983 was used to help evaluate functional aspects of the tree baits for efficient detection, population monitoring and direct control. Data are presented on tree bait distribution, numbers of baits and their placement pattern, and incidence of attacks and attack densities on baited and adjacent unbaited trees.

INTRODUCTION

The recent mountain pine beetle (MPB), Dendroctonus ponderosae Hopkins, outbreak in southwestern Alberta was first detected in 1977 (Hiratsuka et al. 1980). It subsequently expanded rapidly northward along the eastern slopes of the Rocky Mountains, and attained maximum spread some 130 km north of the Canada-United States border by 1980-81 (Hiratsuka et al. 1982). During 1979 and 1980 numerous small but scattered infestations were discovered in the Porcupine Hills in southwestern Alberta, and in the Cypress Hills, an area straddling the southern Alberta-Saskatchewan boundary. The latter area is a distinct forested island isolated from the foothills region by over 200 km of intervening prairie agricultural zone (Newsome and Dix 1968). In addition, small infestation patches were observerd in 1982 in the Alberta foothills (Kananaskis area) directly east of Banff National Park. By 1986, after 10 years of outbreak period, MPB populations had declined to endemic levels at all locations in Alberta and Saskatchewan. Previous historical records of the MPB having occurred in either of these three areas was entirely unknown.

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Prior to 1977, only two observational records had indicated that endemic populations of the MPB existed in southwestern Alberta during the late 1960's and in the early 1970's. The only previous recorded outbreak in Alberta occurred in Banff National Park between 1939 and 1944 (Hopping and Mathers 1945).

During the recent outbreak period in Alberta and Saskatchewan intensive salvage and control programs were initiated by the provinces in 1980-82 (Alberta Forestry, Lands and Wildlife 1986). The control programs consisted of detecting patches of infested trees, followed by destruction of live beetle broods by cutting, burning, bark-peeling and log processing at the mill. Semiochemicals of the MPB had previously been tested successfully in British Columbia and in the Cypress Hills (Borden et al. 1983a, 1983b, 1983c; Cerezke et al. 1984; Conn et al. 1983) and were incorporated initially into the control strategies by three different provincial agencies in 1983. This paper reviews the semiochemical tree baiting strategy from 1983 to 1987, describes the baiting results observed and offers some interpretations of the results.

METHODS AND MATERIALS

Control programs utilizing MPB semiochemicals were deployed in three general areas: Porcupine Hills and adjacent forested lands (PH); Cypress Hills (CH) in Alberta and Saskatchewan and in the Kananaskis (K) area directly east of Banff National Park (fig. 1).

All agencies deployed the same commercially prepared tree bait (Phero Tech Inc., Vancouver, B.C.), consisting of two MPB pheromone components and a host tree monoterpene. The objectives of the baiting program were: to test the tree bait as a reliable detection tool, and thus help reduce costs of subsequent aerial and ground surveys and tree treatments, and to test the baits for survey monitoring to indicate yearly trends of relative MPB abundance and as part of the direct control strategy of beetle population manipulation and/or reduction.

During the first year of semiochemical deployment (1983) an attempt was made to standardize the baiting procedure with the three provincial agencies (Alberta Forest Service, Alberta Parks and Recreation and Saskatchewan Parks, Recreation and Culture) to provide a basis for data analyses and interpretation. In subsequent years the pattern of bait

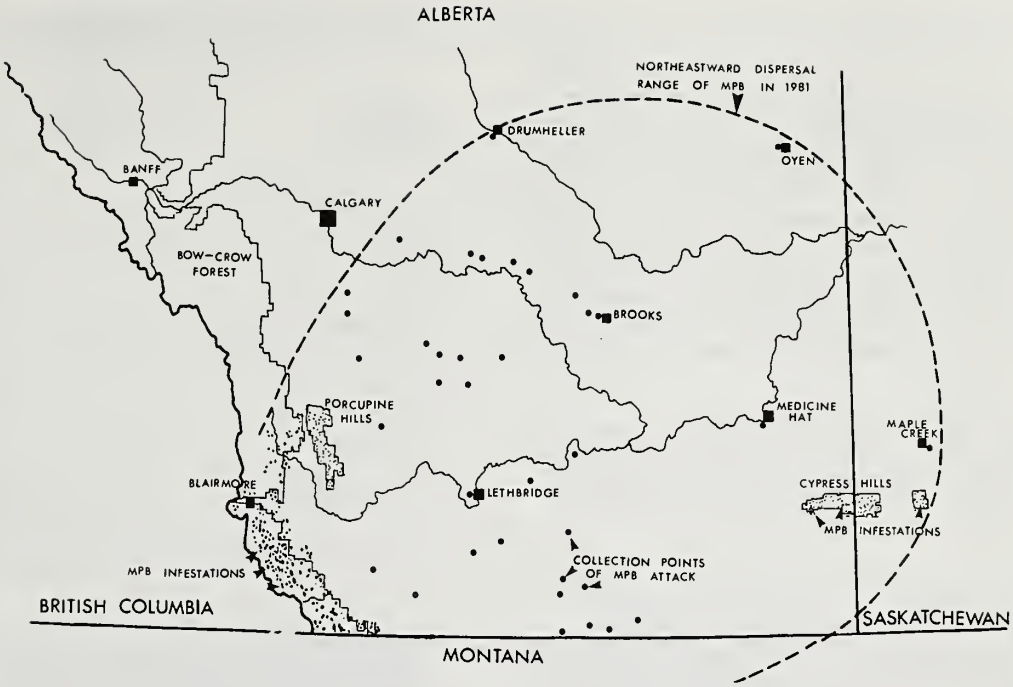

Figure 1--Map of southern Alberta and Saskatchewan showing the maximum extent of D. ponderosae (MPB) infestations in 1981, including the Porcupine Hills and Cypress Hills. Dots indicate collection points of MPB attacks observed on ornamental and shelterbelt planted pines.

distribution remained similar but with some variation in the number and location of baiting sites and in the number of baits deployed per site.

The guidelines adopted by each agency were as follows: baits were placed in mature lodgepole pine (Pinus contorta var. latifolia Engelm.) stands over 60 years of age and with an average DBH of 20 cm or greater in PH, CH and K control areas, and in a few limber pine (P. flexilis James) sites, also in the PH area. Various topographical sites were selected for baiting, including ridge tops, along creeks, on east-facing slopes and adjacent to clearcuts. The baits were placed one per tree on average stand diameter or greater size trees, 2 m above ground level and on the north aspect. Baits were distributed within a number of designated baiting locations (fig. 2) at which 5 to 21 baits were placed 50 m apart in mostly a single line transect or grid pattern. All baits were distributed prior to beetle flight and retrieved in late August or September.

At the end of the flight season all baited and adjacent unbaited trees within a 5-m radius of the baited tree were tallied. In addition, a measure of attack density was obtained on each baited tree and on adjacent unbaited trees by a count of the number of adult gallery initials within two 20x40 cm bark samples removed from each tree, both centered at bait placement level, one each on the north and south aspects. The samples were oriented with the long side vertically positioned on the stem and attack density was expressed as an average of the number of attacks per m^2 of bark surface.

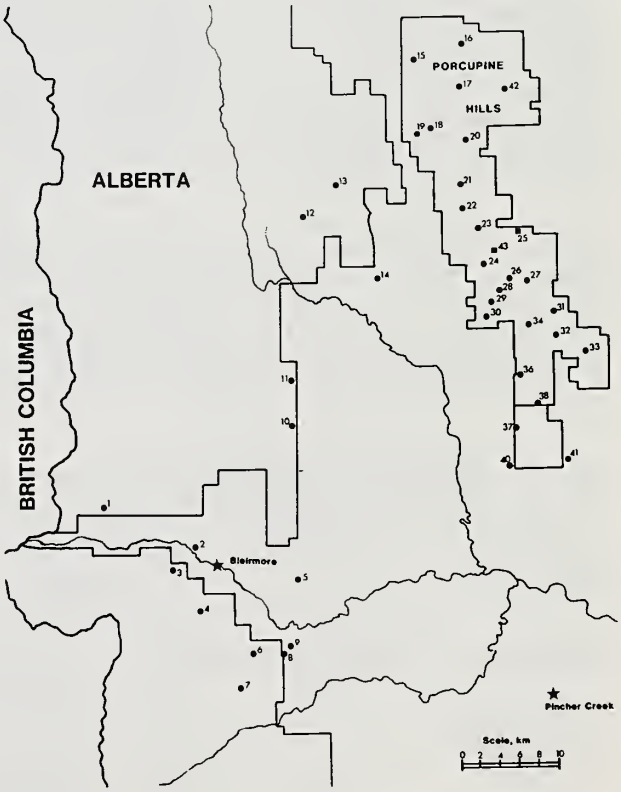

Figure 2--Distribution of D. ponderosae tree baiting sites in southwestern Alberta in lodgepole pine (dots) and limber pine (squares) stands in 1983.

RESULTS AND DISCUSSION

Figure 1 shows the distribution pattern of infestations of the MPB in southwestern Alberta, concentrated in stands of lodgepole pine and limber pine, and in lodgepole pine stands in the Cypress Hills. Collection points of MPB attacks within the agricultural zone were mainly on planted Scots pine (*P. sylvestris* L.), used extensively as an ornamental and shelterbelt species. The suggested northeastward dispersal range of MPB attacks extended some 200-300 km from the nearest population source and is assumed to have been aided by southwesterly flow wind patterns common during the time of beetle flight (Finklin 1986).

The semiochemical baits deployed and the numbers of selected baiting sites during 1983 are summarized in table 1. Numbers of tree baits used in subsequent years in the three control areas are given in table 2.

Populations were relatively high for the MPB in all control areas in 1983 as indicated by the high incidence of attacked baited trees (table 2). Many of the tree baits also influenced the aggregation of beetles onto large numbers of adjacent unbaited trees in over half of the baiting sites. Population declined sharply in most areas after 1984 (Moody and Cerezke 1986). While much of the control efforts of sanitation cuttings and tree bait aggregations to baited sites contributed to the population decline, severe winter temperatures during 1984-85 enhanced the success of the control programs by causing significant beetle mortality. The higher percentage attack incidence in 1987, compared to 1986, probably reflects higher overwinter survival of MPB, reduced numbers of baits in two of the control areas, and possibly the placement of baits into more selected baiting sites known to have populations.

The incidence of attacked baited trees in the Cypress Hills suggests there was a faster rate of decline after 1983 on the Saskatchewan side compared to the Alberta side. This may indicate a more direct population reduction due to concentrations of adult beetles onto baited and unbaited trees.

Table 1--Numbers of *D. ponderosae* tree baits and baiting sites deployed in 1983

Control areas	No. baiting sites	Baits per site (range)	Total no. baits
Kananaskis	7	10 (9-12)	71
Porcupine Hills and adjacent areas	41	10.3 (5-21)	423
Cypress Hills:			
Alberta	12	8.3 (5-20)	100
Saskatchewan	29	11.5 (5-20)	335

Attack densities of baited and adjacent unbaited trees are compared in table 3 and confirm higher attraction rates to the baited trees than to adjacent unbaited trees in all lodgepole pine and limber pine sites where data were available. Also, the percentages of attack incidence on north and south aspects of baited and adjacent unbaited trees were generally similar between the two groups in the different control areas and agree with similar published observations (Amman and Cole 1983).

An attempt was made to evaluate the efficiency of attracting MPB adults onto baited trees placed in a single line transect versus baited trees arranged in a grid (4 x 4 or 4 x 5) pattern. While average attack density was slightly higher on trees baited in a grid pattern the means of the two bait placement patterns were not statistically different. The results of this test, however, may vary with MPB population source and its nearness to the baiting site and with population abundance.

Table 2--Percentage of trees baited with semiochemicals that were attacked by *D. ponderosae* in three control areas during 1983 to 1987

Control areas	1983	1984	1985	1986	1987
Kananaskis and Porcupine Hills areas:	94 [1](494)	48 (2000)	- (1000)	15 (600)	55 (150)
Cypress Hills:					
Alberta:	100 (100)	48 (200)	19 (200)	3 (200)	10 (200)
Saskatchewan:	97 (335)	23 (1000)	10 (800)	0 (500)	1 (300)

[1]Values in brackets indicate the number of tree baits deployed each year.

Table 3--Summary of D. ponderosae attack densities and percentage of attacks on north (N) and south (S) aspects of baited and unbaited adjacent lodgepole pine (LPP) and limber pine (LMP) trees in three control areas in 1983

Control areas	Baited trees			Unbaited adjacent trees		
	Density/m^2	% attacks		Density/m^2	% attacks	
		N	S		N	S
Kananaskis (LPP):	62.4	62.7	37.3	44.2	45.4	54.6
Porcupine Hills and adjacent areas; (LPP):	64.1	53.4	46.6	46.8	56.5	43.5
(LMP):	117.1	47.9	52.1	72.4	50.2	49.8
Cypress Hills;						
Alberta (LPP):	100.2	53.8	46.2	[1]-	-	-
Saskatchewan (LPP):	76.6	54.3	45.7	61.7	51.0	49.0

[1]No data recorded.

A comparison was made between attack densities on baited trees in sites where few or none of the baited trees had associated adjacent unbaited attacked trees and with attack densities on baited trees in sites where 50% or more of the baited trees had adjacent unbaited attacked trees (table 4). This was to examine the likely relationship between MPB population source and abundance and the efficiency of the semiochemical attractants for concentrating beetles on to trap trees. Average attack densities in sites where 50% or more of the baited trees had adjacent unbaited attacked trees were all higher. The data support the idea that the numbers of beetles attracted to semiochemical tree baits are at least partly proportional to the surrounding population, and therefore indicate that the baits can serve as a reliable monitoring tool.

Sites in which different numbers of tree baits were deployed were arranged in classes of numbers of baits per site and plotted against average attack density (fig. 3). The data suggest that highest attack density on baited trees occurred where the numbers of baits was 4 to 6 and decreased to a constant density level when 10 or more tree baits per site were used.

Data on average attack densities in all lodgepole pine baiting sites in the Porcupine Hills were arranged according to topographical features in the landscape to help identify locations that may favor more efficient attraction and/or interception of dispersing MPB. While the data were highly variable some trends are apparent but would require additional field evaluation. Four topographical sites were selected to illustrate possible trends(table 5).

Table 4--Comparison of attack densities on baited trees having few or no adjacent attacked unbaited trees with baited trees having more than 50% of the baited trees with adjacent attacked unbaited trees

Control areas	Few or no adjacents			More than 50% adjacents		
	No. of sites	No. baited trees	Ave. attack density/m^2	No. of sites	No. baited trees	Ave. attack density/m^2
Kananaskis	4	40	33.9	3	30	[2] 97.5
Porcupine Hills and adjacent area	24	257	58.9	9	96	[1] 85.5
Cypress Hills:						
Alberta	9	75	95.7	2	15	[2] 120.3
Saskatchewan	15	175	58.6	12	135	[1]98.5

[1]Means with more than 50% adjacents were significantly higher ($p<0.001$; t-test).
[2]Means not tested because of low numbers of baiting sites.

Table 5--Average attack densities of D. ponderosae on baited lodgepole pine trees at selected topographical sites in the Porcupine Hills in 1983

Topographical sites	No. of sites	No. baited trees	Ave. attack density/m^2
East-facing slopes:	2	13	98.7
Adjacent to creeks:	4	43	95.8
On ridge tops:	5	38	69.9
Adjacent to clearcuts:	3	18	60.0

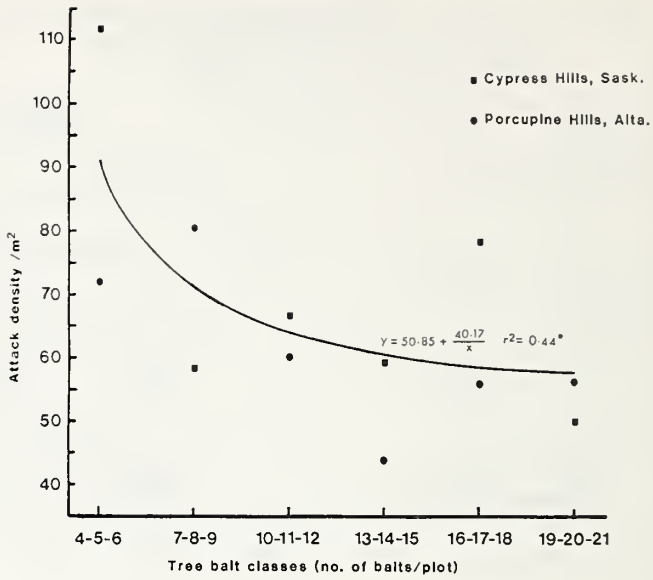

Figure 3--Numbers of tree baits deployed per baiting site (plot) in relation to D. ponderosae attack density on baited lodgepole pine trees.

SUMMARY

The integration of semiochemical tree baits into recent provincial programs to control MPB infestations in Alberta and Saskatchewan provided several important benefits in the overall control strategies. The baits induced aggregation of beetles into specific baiting sites which were often selected for easy access. Hence, infested trap trees could be easily monitored for control by sanitation cuttings during the same year. This allowed more time to be spent on locating isolated pockets of infested trees. The baits may have intercepted dispersing beetles both to and from the control areas. Attack densities on baited and adjacent unbaited trees appeared to vary directly with nearby sources of MPB populations, thus supporting the baits as a monitoring tool.

The baiting of selected sites provided substantial savings in "probe cruising", in search of random infestations, and also in reducing some aerial survey requirements. Depending upon the intensity and distribution of the baits throughout each control area, the aggregation of beetles onto baited and adjacent trees provided an indication of time of beetle flight, of relative population abundance, their geographical distribution and may also have indicated likely sources of populations such as in wind thrown trees and broken tree tops.

Data presented in table 2 suggest the baits may be sufficiently sensitive to detect small changes in population fluctuations when at endemic levels. This is an important aspect where eradication of the MPB from a forested area is the objective. Where only a few MPB induced attacks are successful, the individual galleries can be destroyed without killing the tree. For efficient detection and monitoring use in endemic populations only one, two or three baits per site are likely necessary.

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USE OF CHEMICALS TO PROTECT TREES FROM MOUNTAIN PINE BEETLE ATTACK

Patrick J. Shea

ABSTRACT: Preventative chemical strategies to mitigate the effects of mountain pine beetle depredations are reviewed. Various formulations and rates of carbaryl are shown to be effective in protecting individual lodgepole pine from successful attack by MPB. A 1% formulation of Sevin brand XLR will provide two years of protection. This is one half the registered rate. Results of field tests of various formulations of "pine oil" for individual tree protection indicate highly variable results. No further testing of "pine oil" is recommended because the manufacturer has suspended development.

INTRODUCTION

Chemical intervention to mitigate the effects of mountain pine beetle (MPB) (Dendroctonus ponderosae Hopkins) infestations has a long history. In a review of the history of chemical and mechanical tactics to suppress MPB infestations, Klein (1978) states that an oil formulation of naphthalene was the first chemical used against MPB (Salman 1938). This occurred in the mid-1930s and for the next 30+ years, a myriad of chemical insecticides were tested for MPB suppression. The chemicals tested for use in direct control programs included the following: DDT, lindane, ethylene dibromide, copper sulfate, aldrin, dieldrin, heptachlor and others.

During the mid-1960's it became apparent that efforts to control populations of MPB by spraying individual infested trees was an expensive and futile endeavor. Concurrent with this realization was an increased effort to develop insecticides for individual tree protection. The primary objective of individual tree protection is to protect standing live trees from bark beetle attack rather than kill beetles once they have successfully colonized a tree. Mortality of high-value trees located in campgrounds or other administrative sites can have long-range management effects. The value of these individual trees, cost of their removal, and loss of campgrounds can sometimes justify protecting individual trees until the main threat of an infestation subsides.

Lyon (1965) reviewed many of the early studies designed to prevent attack by bark beetles. In these studies many of the same compounds used in direct control strategies were tested for efficacy in preventing MPB attack of individual trees. Starting in the mid-70's there was a shift away from the chlorinated hydrocarbons and toward newer compounds. This change in direction was the result of at least two considerations: recognition of potential environmental problems associated with the chlorinated hydrocarbons, and discovery by Rodgers (1976) that oil formulations were phytotoxic especially to thin barked species of pine.

Recently research has demonstrated the effectiveness of several water based formulations of carbaryl for protecting individual trees from attack by bark beetles. Smith and others (1977) and McCambridge (1982) clearly demonstrated the effectiveness of a 2% formulation of Sevimol[R] in preventing successful attack by MPB on both lodgepole (Pinus contorta var. latifolia Engelm.) and ponderosa pine (P. ponderosa Laws.). Gibson and Bennett (1985) and Page and others (1985) confirmed these earlier results. It's of interest to note that research by Hall and others (1982) and Haverty and others (1985) demonstrated the same efficacy of water-based formulations of Sevimol for western pine beetle (Dendroctonus brevicomis Hopkins) on ponderosa pine.

There are several objectives to this paper. First, I will review the results of the most recent research on the effectiveness of carbaryl for preventing attack by MPB on lodgepole pine. Second, I will present some preliminary data covering three years of testing with several formations of "pine oil."

CARBARYL

In 1983, Shea and McGregor (1987) rigorously tested two water-based formations of carbaryl for effectiveness in preventing MPB attacks on individual lodgepole pine trees. This study was initiated because Union Carbide Corp. (now Rhone-Poulenc Inc.) had removed Sevimol from the market place. The study had two objectives: to compare the efficacy of Sevin brand XLR (the

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proposed replacement) with Sevimol, and to determine whether lower rates of Sevimol and Sevin brand XLR could provide acceptable protection with the same longevity.

The experimental design and subsequent analysis followed that described by Shea and others (1984). The two formulations were Sevimol and Sevin brand XLR, each applied at 0.5%, 1.0% and 2.0%. About 2.0 gallons of formulated material was applied to each treatment tree (ca. 0.02 gal/ft^2 of bark surface) in the early summer of 1983. The fate of each study tree was followed for two years with a separate set of control trees for each year.

In the fall of 1983, evaluations indicated that all treatments were effective (fig.1) in protecting the test trees from mass attack by MPB. Only one tree in the 0.5% Seven brand XLR treatment group died because of attack by MPB; none of the remaining trees in any treatment group were successfully attacked. Evaluations conducted in the fall of 1984 after two MPB flight seasons clearly indicated that the 0.5% formulations of Sevimol and Sevin brand XLR were beginning to fail (fig.2). However the 1% and 2% dosage rates of both formulations remained effective (>80% survival). This test demonstrated that managers can expect to achieve effective protection of individual lodgepole pine trees with a 1% formulation of either Sevimol or Sevin brand XLR. This concentration is one half the EPA registration rate (EPA Reg No 264-333) and represents a substantial cost savings and reduction of the amount of carbaryl being placed in the high-value,high use site.

Use patterns of this tree protection strategy in MPB infested areas vary greatly. Data from Loomis (1985) and other sources (personal communications) indicated that approximately 100,000 trees were treated for protection from MPB during 1979-1987 (fig.3). More than 80% of these trees were treated with a 2% formulation of carbaryl (probably Sevimol). However, during the field seasons of 1986, 1987, and 1988, USDA Forest Service individual-tree-protection programs have utilized the 1% concentration of carbaryl. For instance, personnel on the Deerlodge (1986) and the Flathead (1987) National Forests treated 1800 and 1200 campground trees, respectively, and report approximately 100% protection (personal communication with Region 1 FPM). Obviously these data have important economic and environmental implications.

PINE OIL

Recently there has been considerable interest, effort, and discussion concerning the use of "pine oils" as a repellent for protecting individual trees from attack by various species of bark beetles. "Pine oil" is a generic term referring to a complex mixture of naturally occurring or synthetically derived secondary and tertiary terpene alcohols and other terpene hydrocarbons. The naturally processed "pine oils" are refined by-products of the pulp and paper industry.

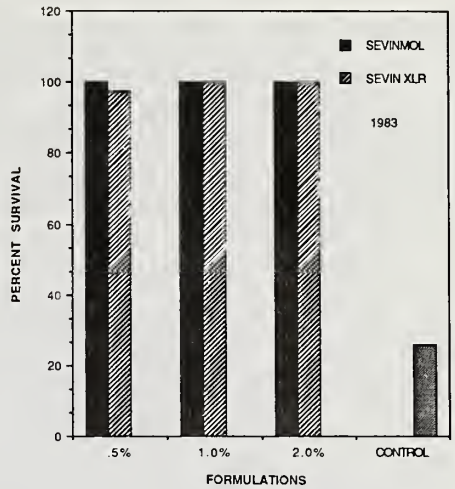

Figure 1--First year efficacy results of various rates of Sevimol and Sevin brand XLR after the 1983 field season.

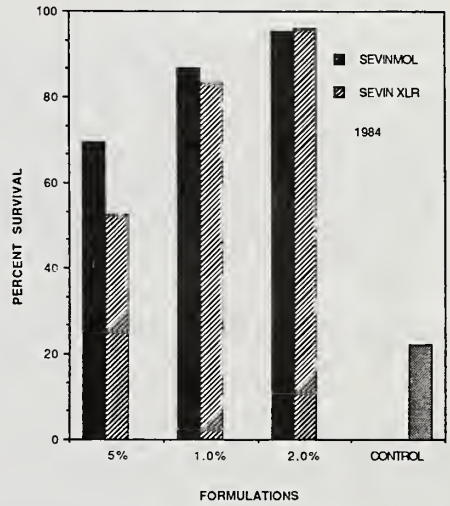

Figure 2--Second year efficacy results of various rates of Sevimol and Sevin brand XLR after 1984.

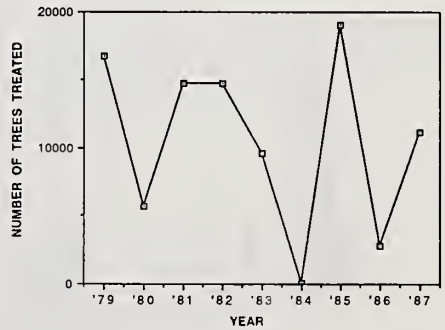

Figure 3--Use patterns of preventive sprays for mountain pine beetle 1979-1987.

Nijolt and McMullen (1980) first demonstrated that "pine oil", formulated as Norpine 65, could effectively prevent MPB from successfully attacking individual lodgepole pine. This was followed by a number of published reports indicating similar results on different populations of MPB (McMullen and Safranyik 1985; Richmond 1985) and other species of Dendroctonus (Nijolt and others 1981).

After considerable laboratory studies conducted to isolate the active fractions of Norpine 65, Mark McGregor (R-1, Entomologist) and I initiated field experiments to test the efficacy of various formulations for protecting individual trees from attack by MPB. These field tests were conducted because it was concluded, after discussions with representatives of Northwest Petrochemical Corp., that registration of Norpine 65, or any other unrefined formulation of pine oil, by EPA for individual tree protection would be a near impossibility. This conclusion was reached based on the nature of the Norpine 65 formulation with its numerous components, some of which had never been indentified, and the probability that each of these components would have to be subjected to numerous toxicological studies.

The design of these experiments follows that described earlier in Hall and others (1982) and Shea and others (1985). The tests were conducted during 1984-1986 in the Flathead National Forest of northwestern Montana. No synthetic baits were used in any of the experiments. A confidentiality agreement between the USDA/Forest Service and Northwest Petrochemical Corp. prevents, at this time, disclosure of specific contents in each formulation.

The results of 1984 tests are presented in figure 4. Greater than 60% of the control trees were successfully attacked indicating rigorous test conditions. None of the pine treatments met the predetermined success criteria that at least 24 of the 30 trees must survive to test the H_0:S(survival) $\geq$ 90% against H_a:S = 70%. Given a sample size of 30-35 trees these parameters provide a conservative binomial test (alpha = .05) to reject H_0 when more than six trees die. The Norpell, Fraction B and Fraction C formulations are all distillation tower refinements of Norpine 65P. The results obtained from Fraction B and Fraction C suggest that perhaps some attraction was occurring that resulted in higher attack rates on trees within these treatments when compared to the controls.

Results of the 1985 field experiment (fig. 5) were similar to those obtained in 1984 in that all the treatments failed to provide adequate protection given the criteria described previously. However two things are of obvious interest. First the Norpine 65P formulation performed very poorly. Second the formulation Norpine M+O provides some suggestion of effect, given the high attack rate on the control trees and the percentage of trees not attacked or stripped attacked.

Finally, the results of the 1986 field experiments are presented in figure 6. The reduced sample size seriously affected the strength of the conclusions and was the result of a loss of trees due to firewood cutting and other uncontrolled events. Both the Norpine 65P and Norpine Poly M indicate considerable effectiveness. The protection provided by the Norpine Poly M formulation is especially noted because fully 80% of the test trees were not attacked at all in contrast to the Norpine 65P treatment where only

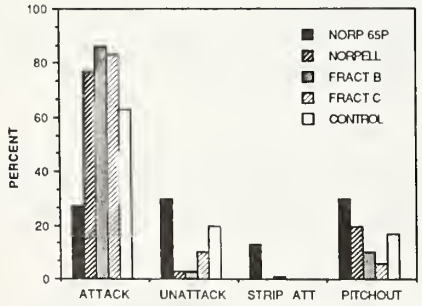

Figure 4--1984 results of various formulations of "pine oil" to prevent MPB attack on lodgepole pine.

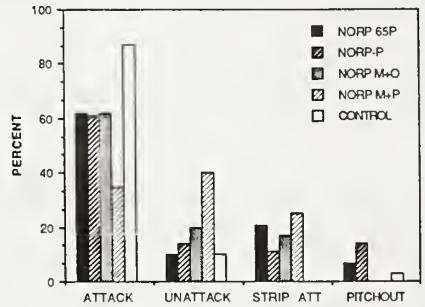

Figure 5--1985 results of various formulations of "pine oil" to prevent MPB attack on lodgepole pine.

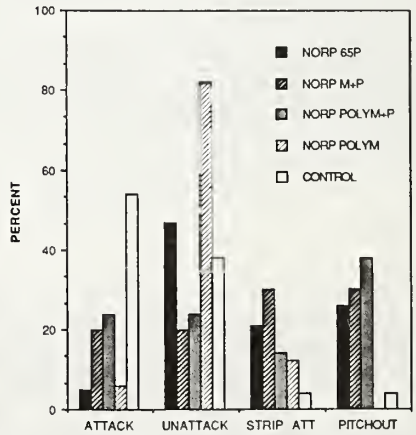

Figure 6--1986 results of various formulations of "pine oil" to prevent MPB attack on lodgepole pine.

47% of the trees were unattacked. These results would be especially encouraging if not for the fact that Northwest Petrochemical Corp. has experienced corporate difficulties unrelated to "pine oil" production and has decided to forego further development of this product.

Summarizing, preventive sprays for protection of individual high-value trees from attack by MPB is successfully employed throughtout the affected areas. Recent research and operational use has demonstrated that a 1% formulation (one half the registered rate) of carbaryl provides excellent protection. At the present time "pine oil" formulations do not appear promising as an alternative to insecticidal preventive sprays.

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REGISTRATION STATUS OF BARK BEETLE SEMIOCHEMICALS

Dennis R. Hamel

ABSTRACT: Tests of the semiochemicals verbenone and 3-methyl-2-cyclohexen-1-one (MCH) are continuing under experimental use permits. It is hoped that results will lead to registration consistent with the Federal Insecticide, Fungicide, and Rodenticide Act and the National Environmental Policy Act and use of these bark beetle semiochemicals as alternatives to conventional chemical pesticides.

INTRODUCTION

A full understanding of the processes leading to the registration of a compound as a pesticide requires the definition of several terms and the placement of them in proper context with their associated laws and regulations. This paper defines terms such as: a pesticide, pesticide research, experimental-use permit, pesticide registration, and exemption in the context of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), as amended. It also defines environmental analysis, scoping, categorical exclusion, environmental assessment, and environmental impact statement as related to the National Environmental Policy Act (NEPA). The paper concludes with an update of the registration status of two semiochemicals--verbenone, the antiaggregating pheromone of the mountain pine beetle (MPB), and methylcyclohexenone (MCH), the antiaggregating pheromone of the Douglas-fir beetle (DFB).

FIFRA

FIFRA is a Federal law that was passed by Congress in 1972 and substantially amended in 1974 and 1978. New revisions were considered in 1987 and 1988 but Congress has been unable to reach agreement on new changes to the Act. FIFRA is administered by the U.S. Environmental Protection Agency (EPA) and it provides national guidance for and regulation of the registration, manufacture, transportation, and use of all pesticides (herbicides, fungicides, fumigants, insecticides, rodenticides, etc.). FIFRA defines a pesticide as any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest (insect, rodent, plant, or other unwanted organism).

Section 3 of FIFRA provides guidance on the data required to register a pesticide. Data gathering is research. Preliminary research or testing is usually done in the laboratory and is called screening for potential pesticidal activity. Later, greenhouse and/or limited outdoor tests are done to further confirm pesticidal activity. While testing is being done to determine the value of a substance for pesticidal purposes, and when applications are on a cumulative total of less than 10 acres, a material is not considered a pesticide and no paperwork under FIFRA is required. However, once an active ingredient is determined to be efficacious and there is an interest in examining its potential for future operational use, then an experimental use permit (EUP) is required.

The purpose of EUP's is to provide EPA some oversight (FIFRA Section 5) during the generation of data necessary to support an application for full registration (FIFRA Section 3). The process is also intended to prevent adverse environmental impact by preventing the indiscriminate use of potentially dangerous materials without the restraint and control of regulatory protocols that prescribe plot size, geographic location, and amount of active ingredient intended to be used under the EUP. When a material is being evaluated for its pesticidal potential on more than 10 acres, EUP's are essential. This goes for conventional chemical pesticides, biologicals, and semiochemicals. Exceptions exist when the Administrator of EPA grants an exemption.

Such was the case in 1987 when EPA, after long negotiations with the USDA Forest Service and Phero Tech, Inc., changed its policy and allowed tree baits, which had previously required registration, to be exempt. EPA has not, however, exempted semiochemicals that are sometimes formulated as beads and used in broadcast applications.

NEPA

NEPA is a Federal law passed by Congress in 1969 to encourage Federal agencies to conduct their programs in ways that will create and maintain conditions under which people and nature can exist in productive harmony now and in the future. It also requires a systematic, interdisciplinary approach to planning and decision making for

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actions that may affect the quality of the human environment. Federal agencies are required to study, develop, and describe appropriate alternatives to proposed courses of action under NEPA.

The process of analyzing a proposed course of action and developing alternatives is called environmental analysis. The method of collecting public input (in terms of issues, concerns, and opportunities) is called scoping. Scoping determines the extent of environmental analysis necessary. The result of these two activities leads to documentation of a decision.

Depending on the nature of a proposed Federal agency project, NEPA documentation may take one of three forms: (1) categorical exclusion (CE), (2) environmental assessment (EA), or (3) environmental impact statement (EIS). Categorical exclusions are reserved for actions that, based on both experience and environmental analysis, will have no significant impact on the quality of the human environment, individually or cumulatively (e.g., administrative road closures, construction of low-impact facilities, repair and maintenance, etc.). It is not a good practice to use CE's for most pesticide-related activities. Environmental assessments are used to document the analysis of an action not categorically excluded from documentation but for which the need for a more extensive environmental impact statement has not been determined. EIS's are comprehensive reviews of factual information that provide a responsible official with all of the information, necessary to make an informed decision. Some EIS's contain risk assessments and worst case analyses when they deal with subjects about which there is scientific uncertainty or unknown information. This is often the case with pesticides.

BARK BEETLE SEMIOCHEMICAL REGISTRATION STATUS

The USDA Forest Service (FS) has pioneered or assisted in pioneering research on the identification and development of several bark beetle semiochemicals. For example, in the early 1970's FS researchers identified, isolated, and synthesized 3-methyl-2-cyclohexen-1-one (MCH), the antiaggregating pheromone of the Douglas-fir beetle. More recently the FS cooperated in the research and development of 4,6,6-trimethylbicyclo (3.1.1) hept-3-en-2-one or verbenone, the antiaggregating pheromone of the mountain pine beetle.

MCH

Initial laboratory testing of MCH by the FS did not require FIFRA paperwork; however, in 1978 the FS requested an EUP from EPA. The EUP was granted (No. 27586-EUP-23) and the FS expects to continue operating under an extension to this EUP until May 1990.

In 1986, the FS, based on data collected under the EUP, requested full registration of MCH. In 1988, EPA notified the FS that additional research was needed. Unable to conduct the necessary research itself, the FS requested input from interested parties in the private sector by advertising in the Commerce Business Daily (June 8, 1988). Four firms expressed interest in production and marketing of MCH and negotiations are in progress to transfer this technology under the auspices of the Stevenson-Wydler Technology Transfer Act. Use of MCH is very limited at present, and no NEPA documents covering use of this compound have been prepared to date.

VERBENONE

Basic research on verbenone has been conducted primarily in Canada at Simon Fraser University and at Phero Tech, Inc.; however, the FS has been an active cooperator in the research and development of this MPB-antiaggregating pheromone. In 1988, Phero Tech, Inc. requested and was granted an EUP (No. 56261) for evaluation of bubble cap (EUP-1) and bead (EUP-2) formulations. These EUP's will serve to facilitate small-scale field studies of verbenone over the next 2 years. Currently the FS is cooperating on a replicated research study in Regions 1, 2, 4, and 6 as described by Amman and others at this meeting. An EA was developed by the Intermountain Research Station for this effort.

It is hoped that, consistent with FIFRA and NEPA, the results of these efforts will lead to the future registration and use of bark beetle semiochemicals as viable alternatives to conventional chemical pesticides.

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Includes 25 papers summarizing latest information on risk assessment, planning, management strategies, and suppression practices for the mountain pine beetle, a major cause of lodgepole pine losses in large forest areas of the Western United States and Canada.

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